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The Golden Nematode of Potatoes

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THE PROBLEM

Once established in a field, the golden nematode of potatoes has never been eradicated despite crop rotation and soil fumigation. Control measures that have been worked out permit normal crops of potatoes and tomatoes—the only two commercially grown vegetables it attacks—but they must be repeated indefinitely, and they do not prevent spread of the pest.

The golden nematode is recognized throughout the world as one of the most difficult of all crop pests to control. Zoologists are taught that specialized organisms are unable to survive adverse conditions. Yet the golden nematode, one of the greatest specialists among plant nematodes, has one of the highest survival values of any organism. It can remain dormant for many years in the absence of its host, and young nematodes are protected by a durable cyst wall that acts as a protection against adverse conditions such as drying.

For these reasons, the course of the disease organism is inexorable. Scattered nematodes attain maturity, reproduce, and thus increase in numbers. The slow build-up of population and spread of the disease is undramatic; it appears most innocuous in the field. But the population increases like compound interest and eventually overflows.

The very innocuousness of the disease in its early stages is an aid to survival of the organism. Neither potatoes nor tomatoes are disfigured by the pest to betray its presence. Crop reduction as a result of the scattered nematodes is negligible. The build-up, being slow, may require several years after the introduction of the organism in a field before there is noticeable crop injury and reduced yield. A great paradox is that nematodes that cause drastic crop losses do not mature on the roots. They attack in such large numbers that they kill the roots, deprive themselves of food, and therefore die prematurely. The scattered nematodes that remain then start the cycle over again.

HISTORY OF THE DISEASE IN EUROPE[1]

The existence of a soil-borne debilitating disease of potatoes was recognized in parts of northern Europe prior to the identification of the causal organism, *Heterodera rostochiensis* Wollenweber, in 1923 (*60*).[2] Kühn (*38*) recorded the existence of the golden nematode of potatoes in one isolated spot in Germany as early as 1881. Zimmerman (*61*) determined that "soil sickness" of potatoes in the Mecklenburg area of Germany was caused by a nematode in 1913. At this time commercial crop damage was quite extensive. By 1923 crop damage due to this pest was so serious throughout northern Germany that regulatory measures were put into effect.

Taylor, according to Leiper (*39*) and Strachan and Taylor (*55*), first recognized the disease in Yorkshire, England, in 1917. According to Strachan and Taylor (*55*) the disease history goes back to one small patch of debilitated potatoes observed by Strachan in 1904. They further state, "Subsequently, frequent crops of potatoes were taken, and by 1917 'dab' had crept over the entire field. By this time also, it had become very troublesome in a second field (B). Here the first patch of infection was seen in 1914, or ten years after the disease was first noticed on the farm. This was not the end, for in 1923, the scourge broke out in a third field (C), in this instance as several patches." According to Leiper (*39*) the disease caused severe crop loss in Cambridgeshire and Cumberland in 1919. By 1940 practically all British potato-growing districts were known to have foci of infestation and many of the best potato lands had become unproductive.

In Sweden the disease was first found at Hogsjo in 1922, and in 1943 Holmberg (*35*) reported its presence in 156 communities from the southern limits of Sweden to Stockholm and Degerfors Bruk. Disease history in this country indicates spread from local gardens to commercial farms.

The golden nematode of potatoes was discovered in Northern Ireland by Carroll (*8*) in 1922; in Denmark in 1932 (*1, 2*). Published reports of the existence of this disease in Netherlands, Belgium, France, and

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[1] Information published after 1947 not included.

[2] Italic numbers in parentheses refer to Literature Cited, p. 45.

Finland have come to notice. Private communications indicate its presence in Switzerland also.

Regulatory measures forbidding the importation of potatoes from infested areas have been adopted by Italy, the Union of Soviet Socialist Republics, Norway, Sweden, Lithuania, and Estonia.

Germany has enforced a strict crop-rotation schedule on infested lands for many years. Holland, Denmark, Sweden, and Ireland forbid the planting of potatoes on infested land.

HISTORY OF THE DISEASE IN THE UNITED STATES

The golden nematode of potatoes in the United States was first discovered in 1941 in Nassau County, Long Island, N. Y. (fig. 1), by Cannon (7), a Cornell University graduate student attached to the local farm bureau. The causative organism was identified by the writer and other members of the Division of Nematology. The field in which it was originally discovered presented a history of isolated spots showing poor potato yields as early as 1934. These spots multiplied and enlarged so that by 1938 commercial losses were sustained and the farm operator began a series of repeated requests for soil analysis. In 1941 the golden nematode was found, not in the soil, but on the roots of growing potato plants (fig. 2). At that time the entire original field was infested, and in an adjoining field marked injury was apparent.

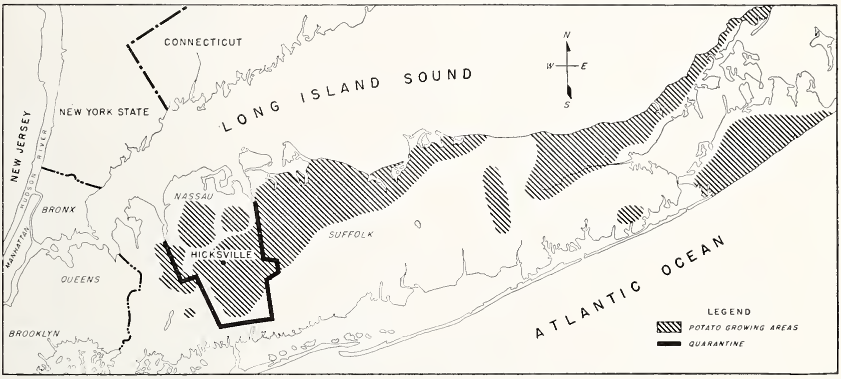

FIGURE 1.—Map of Long Island, N. Y., showing areas of commercial potato production and golden nematode quarantine zone as of July 1, 1948.

In 1942, 13 additional fields were found infested, two of which were farmed by the operator of the field in which the disease was first discovered. In 1943 a survey disclosed 8 additional infested fields, 4 being farmed by the same operator as the original field.

Beginning in 1944 much more extensive surveys were made by the Division of Domestic Plant Quarantines, Bureau of Entomology and Plant Quarantine, and the Division of Nematology, Bureau of Plant Industry, Soils, and Agricultural Engineering, of the United States Department of Agriculture, cooperating with various States, but no new loci of infestation have been discovered in this country, though

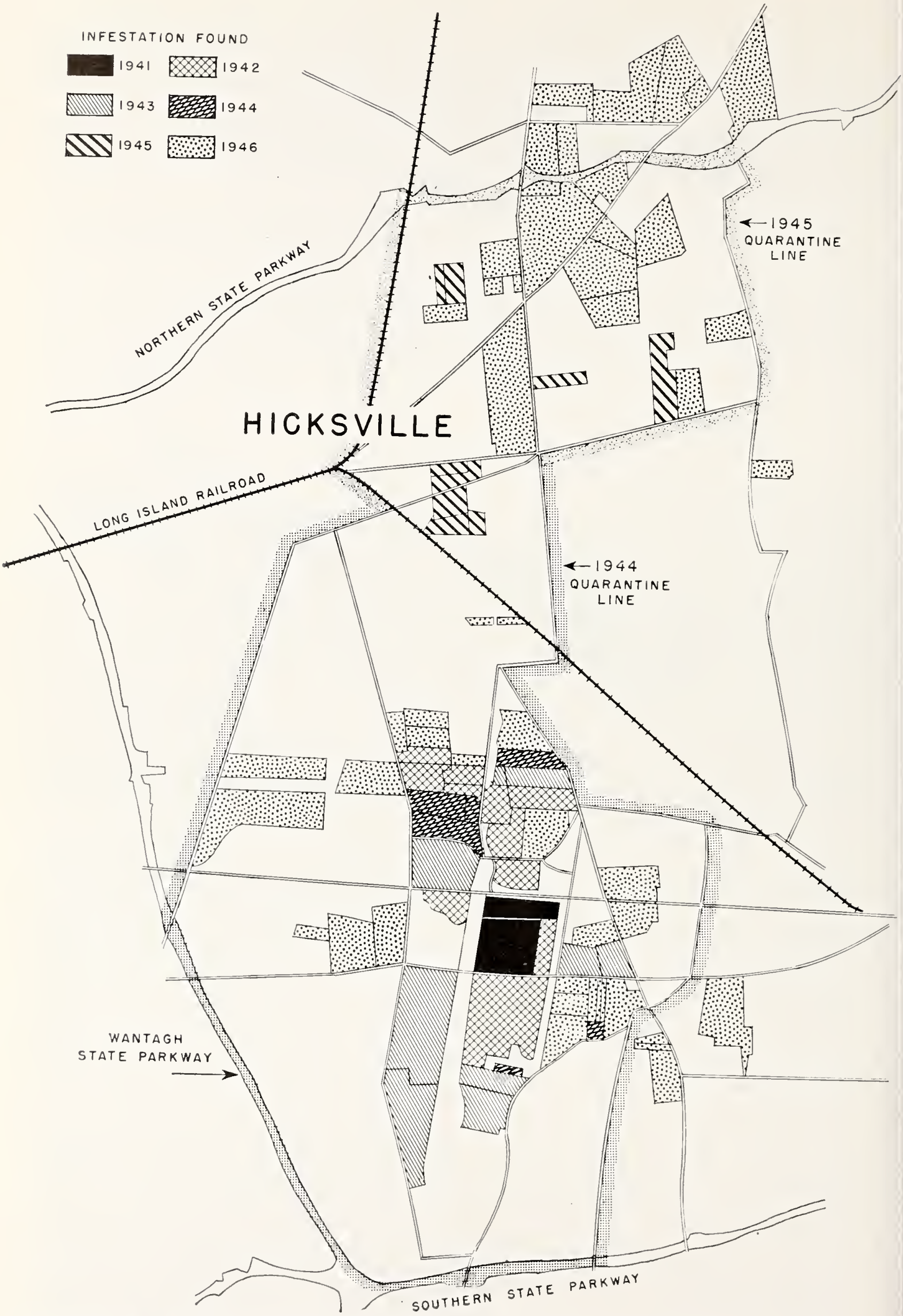

Figure 2.—Map of the Hicksville area of Long Island, showing fields infested according to year the property was determined to be infested, 1941–46.

fields suspected to be infested and refuse dumps of potato soil at packing plants have been examined in all of the principal potato-growing sections of the United States. However, rigorous search in cooperation with the New York State Department of Agriculture and Markets since 1944 has increased each year the area known to be infested on Long Island (table 1 and figs. 1 to 4).

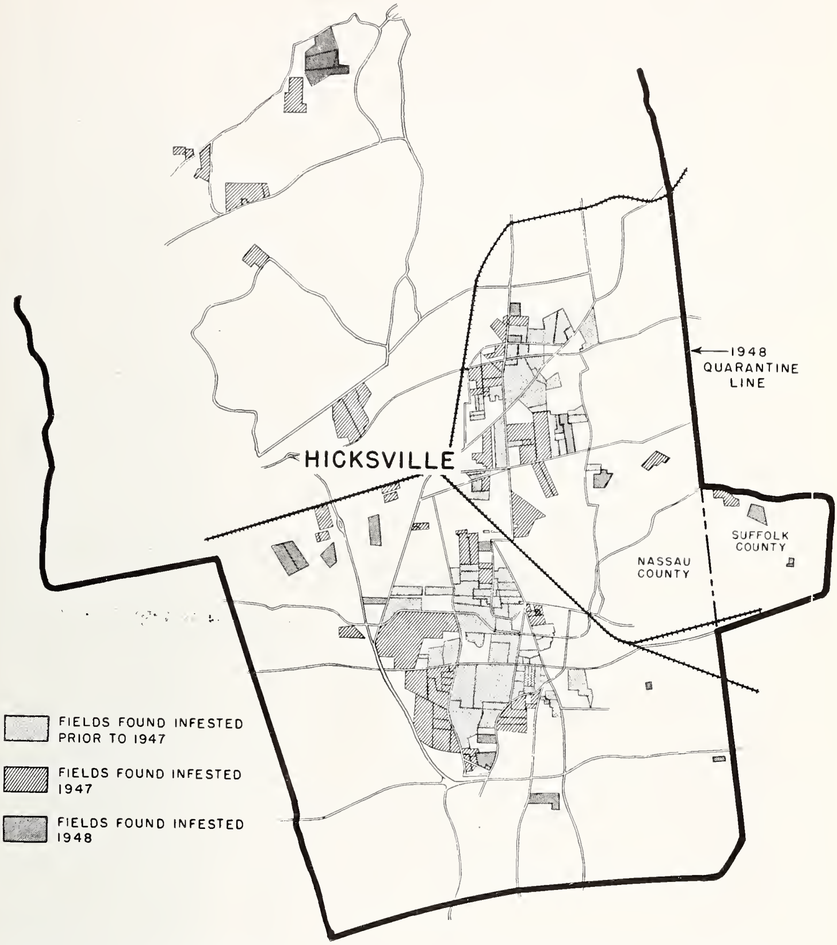
HICKSVILLE
1948 QUARANTINE LINE
SUFFOLK COUNTY
NASSAU COUNTY
FIELDS FOUND INFESTED PRIOR TO 1947
FIELDS FOUND INFESTED 1947
FIELDS FOUND INFESTED 1948

Figure 3.—Map of the known golden nematode-infested properties in New York, July 1, 1948.

The increase in acreage is partly due to gradual build-up of the nematode populations to what might be termed a "discovery level" and partly to spread before and during the period prior to establishment of a quarantine. However, there seems to be little doubt that minor local spread is continuing; for example, a few cases have been discovered in which infested topsoil from the quarantined area was delivered to nurseries of the adjoining Queens County. The picture is not really

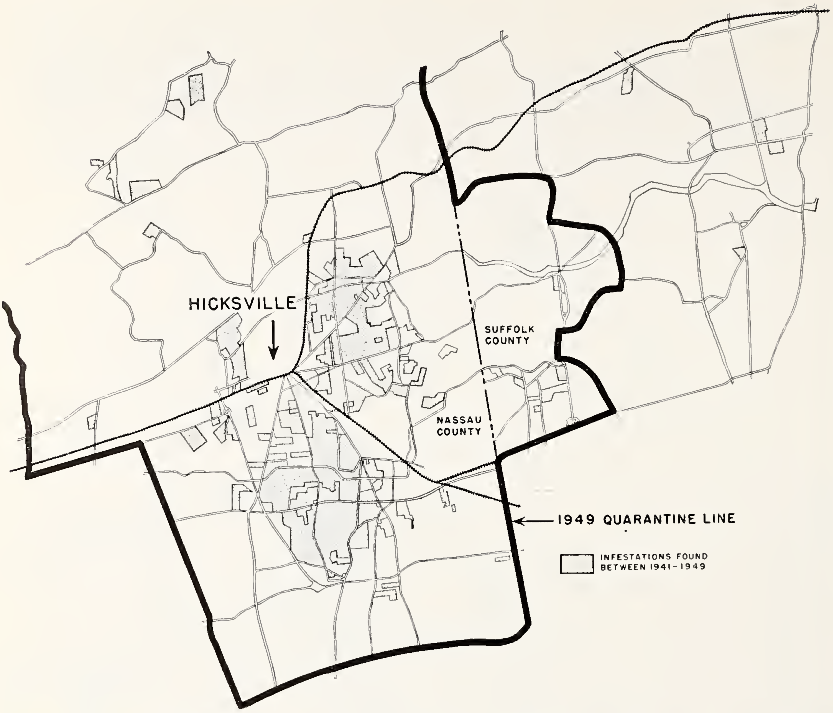

FIGURE 4.—Map of the known golden nematode-infested properties in New York, September 20, 1949.

TABLE 1.—*Fields infested with the golden nematode of potatoes on Long Island, N. Y., 1941–49* [1]

Year	Fields discovered infested		Total number of acres known to be infested
	Number	Acreage	
1941	2	115. 66	115. 66
1942	9	541. 86	657. 52
1943	8	437. 36	1, 094. 88
1944	5	142. 98	1, 237. 86
1945	5	165. 88	1, 403. 74
1946	41	1, 656. 50	3, 060. 24
1947	53	2, 823. 28	5, 883. 52
1948	33	1, 251. 61	7, 135. 13
1949	29	1, 013. 15	8, 148. 28
Total, 9 years	185	8, 148. 28	

[1] Data furnished by Division of Domestic Plant Quarantines, U. S. Department of Agriculture.

quite so alarming as might be supposed from the maps, as much of the most heavily infested land has now been converted to private home building, and this trend is continuing to such an extent that the greater part of the heavily infested lands will probably be permanently removed from agriculture.

Present evidence indicates that the field originally found infested was probably the first field into which the disease had been introduced. Certain procedures in farm operation were a major factor in the local spread of the disease, as more than 20 additional fields farmed by the same operator have since been found to be infested.

In 1944 the New York State Department of Agriculture and Markets invoked regulatory measures banning the use of potatoes from infested fields for seed purposes and regulating the sale of topsoil from such fields. These regulations also governed the cleaning and movement of farm equipment, potatoes and other root crops, and nursery stock.

In 1949 potatoes from known lightly infested land (fig. 4) were washed and treated at 132° F. for 5 minutes. Thereafter they were allowed to be marketed in paper bags without further restriction.

ORIGIN OF THE GOLDEN NEMATODE

The golden nematode of potatoes is known only in north-central and northwestern Europe and in one locality in the United States. It parasitizes potatoes, tomatoes, and certain solanaceous weeds including *Solanum dulcamara* L., and *S. sarachoides* Sendner (*4*). There is considerable diversity in the suitability of hosts, even within the tuber-forming solanums. Present evidence seems to indicate that this nematode originally parasitized some solanaceous garden weed or ornamental, becoming established in potato fields in Germany and England between 1881 and 1904. Infestations in Northern Ireland, Sweden, Denmark, and Netherlands may have originated as a result of infested soil accompanying seed potatoes from England and Germany or they might have developed as parallel transfers from an unknown original host plant.

It is extremely difficult to establish the source of such infestations, as many years are usually required after the introduction of the disease organism in a field before crop losses cause the nematode to be called to the attention of scientific workers. The entire known infestation in the United States appears to stem from a single field, the date of introduction into that field having been prior to 1931. The source has not been established.

Inspection of soils about the roots of nursery plants and other material for propagation by the Division of Foreign Plant Quarantines has shown that the golden nematode of potatoes, as well as numerous other species of the genus *Heterodera*, are being offered for entry into the United States regularly at various ports. Quarantine regulations prohibit the entry of plant material when accompanied by soil, except when it originates in Canada. Even when not accompanied by soil, entry is refused if golden nematode cysts are found as contaminants. Points of origin of intercepted golden nematodes include the British Isles and most western European countries.

THE DISEASE ORGANISM

The nematode *Heterodera rostochiensis* is usually called the potato root eelworm, potato eelworm, or potato nematode in Europe. Since there are several nematodes that are economic problems to the potato industry of this country and since State bulletins on "potato eelworm"

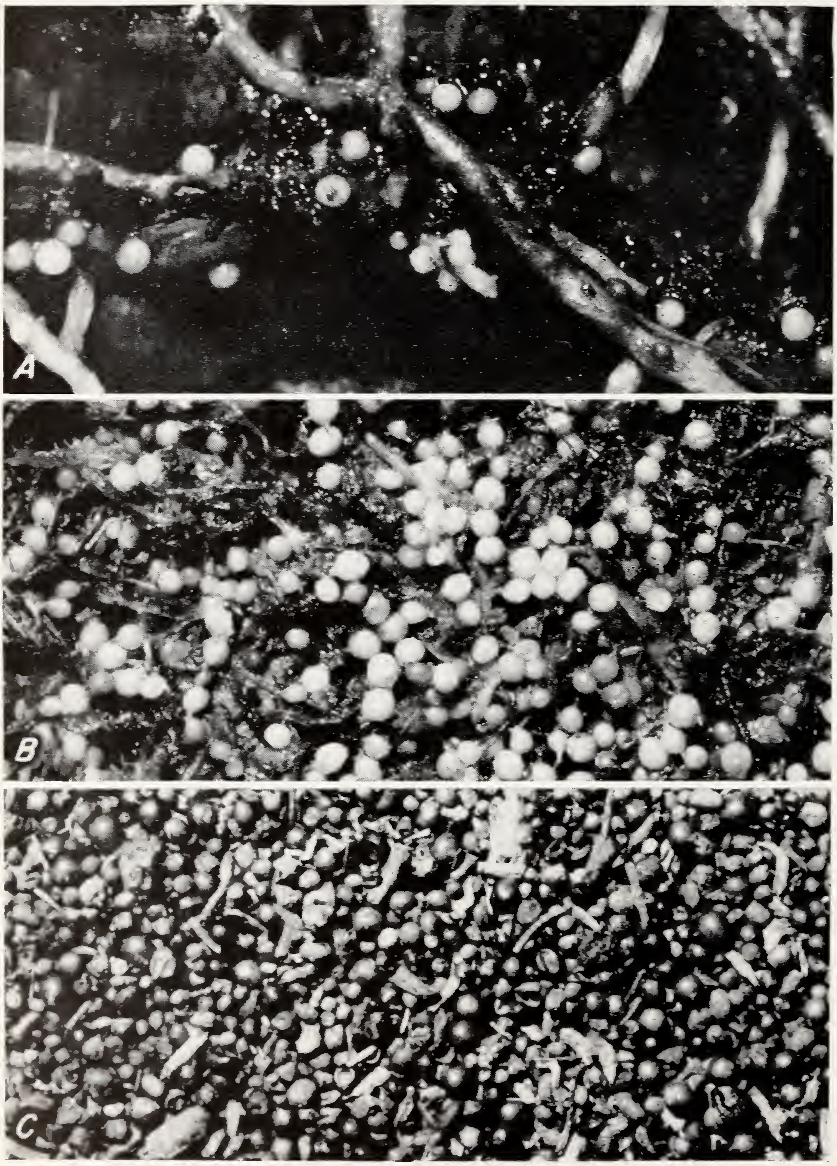

FIGURE 5.—Golden nematode females: *A*, Attached to potato roots; *B*, washed free from roots; *C*, mature cysts washed from potato soil.

usually refer to root-knot nematodes, the term "golden nematode" of potatoes for *Heterodera rostochiensis* was adopted. This organism is so named because when potatoes are in bloom the female nematodes (fig. 5, *A*) attached to the roots have a rich golden color. In late season these females turn red brown, the body wall forming a tough, resistant cyst for the protection of the enclosed eggs.

These cysts, which are about the size of a pinhead, easily become dislodged from roots or tubers and are to be found loose in the soil (fig. 5, *C*), where, according to European records, they persist up to 15, or perhaps 20, years. The eggs have not been found to hatch in the same season in which they were produced, even in the presence of growing potato plants. In the spring, when weekly mean soil temperatures reach 60° F. and when the cysts are stimulated by leachings from growing potato roots, some of the eggs hatch and larvae leave the cyst through the vulvar opening. In the absence of proper host plants or when temperatures are inadequate, eggs and larvae may remain dormant. According to Franklin (*30*) this condition may persist at least 8 years.

Under favorable conditions the microscopic eel-shaped larvae (fig. 6, *A*) migrate from the cysts and enter growing roots, stolons, or tubers. In the roots they take up a position next to the vascular system. Here they pass through a series of growth stages marked by molts. The rapidity of development depends on temperature, gravid females being found 38 to 48 days after root invasion. In the course of development the female swells, breaking through the root surface first as a pale transparent body, later becoming opaque and pearly white, gradually turning a rich golden color, and finally turning red brown with age. The female is sedentary from the time it enters the root. Males, on the contrary, swell only slightly in the course of their development, then resume an eel-like, or serpentine, form and migrate to the females where they may be found clustered when the female is in the white stage (figs. 7 and 8).

HOST-PARASITE RELATIONS

Symptoms

Distinctive specific symptoms of *Heterodera rostochiensis* infection of potatoes do not exist. In severe infections (fig. 9, *A*) the plants are marked by delayed emergence, stunting, lack of bush development, general unthriftiness, early maturity, and early death. The root system is characterized by many roots, with branching not only at the level of the seed piece but sometimes even on the stem in the form of one or two root brackets. In extreme cases the foliage may be lighter in color. Goffart (*34*) also reports brown discoloration of leaf tips, the lower leaves dying off, and the upper leaves exhibiting brown discoloration and rolling. Such marked symptoms have not been associated with this disease in the United States, perhaps because the infestation is not so old or perhaps the climate and varieties planted do not cause the same plant response.

Symptoms certainly vary greatly from year to year in the same field. In the studies herein discussed, this phenomenon is associated

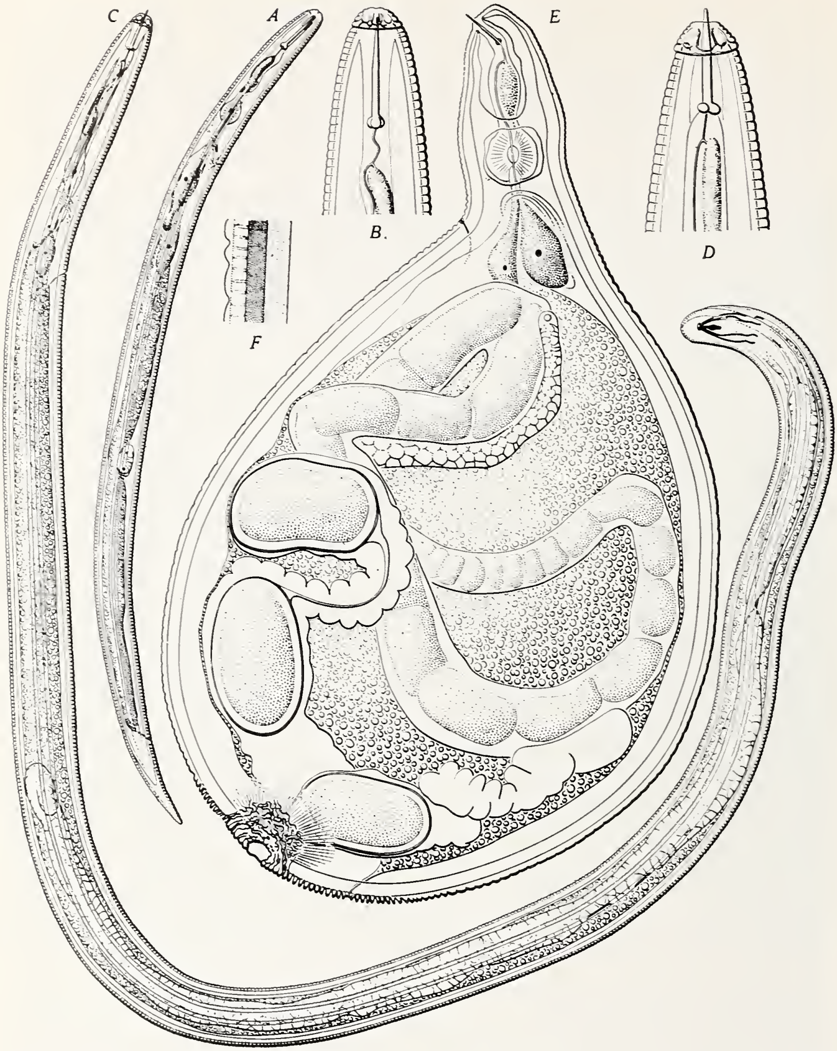

FIGURE 6.—The golden nematode of potatoes, *Heterodera rostochiensis* Wollenweber, 1923: *A*, Infective larva, hatched from egg; *B*, head of infective larva; *C*, adult male; *D*, head of adult male; *E*, young adult female; *F*, section of cyst wall. *A*, *C*, and *E*, × 250. *B*, *D*, and *F*, × 580.

with date of attack, planting date, and variety. As first noted by Carroll and McMahon (*9*) damage is moderate if the plant has already established a good root system before attack. Contrariwise, in years of prolonged winter (extended period below 50° F., weekly mean temperature) followed by warmer weather (temperatures above 60° F.) the plant has had no opportunity to establish its root system before invasion by the nematodes. In such years delayed emergence and stunting may be expected. Early dying of vines is naturally associated with dry weather, as the damaged root system makes the plant more susceptible to adverse growing conditions.

During 1946, a good potato year on Long Island, N. Y., there were 4 weeks of mean temperature between 50° and 59° F.; injury caused by the golden nematode was at a minimum, but nevertheless, injury could be detected on the late variety Green Mountain in locations of exceptionally heavy infestation (fig. 9, *A*). A severely injured plant (fig. 10, *B*) was selected, and a count was made of the number of new gravid females washed from the roots. There were 31,307, or approximately 900 females per gram of root. In contrast, plants with an

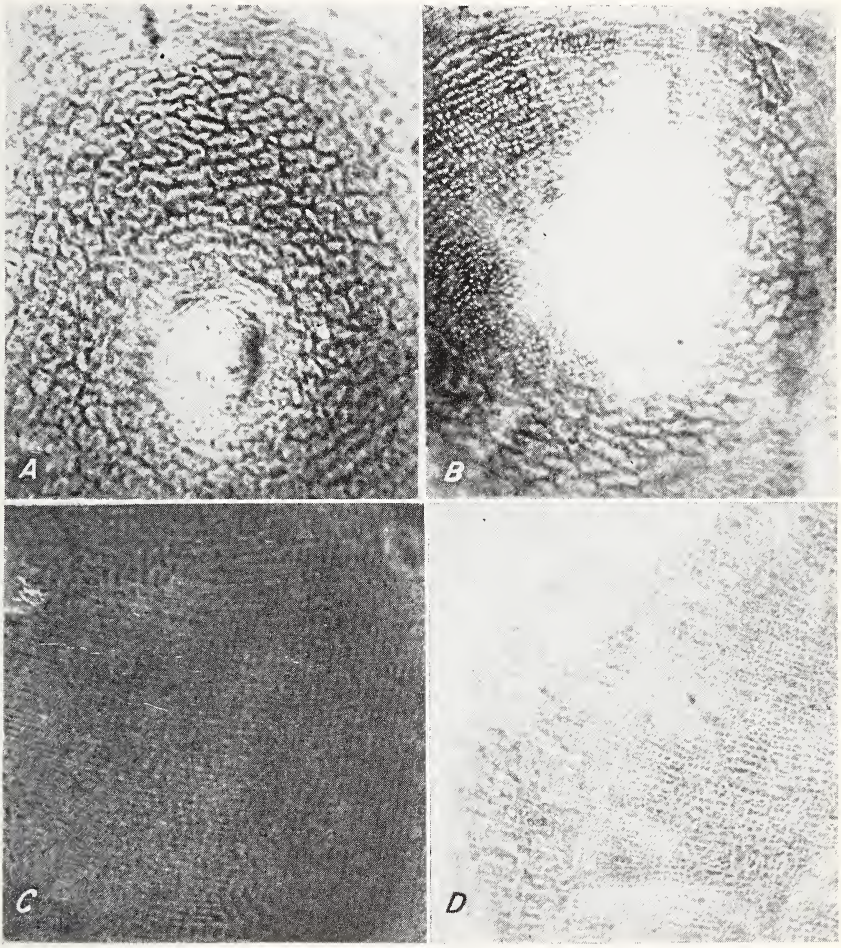

FIGURE 7.—The cyst wall of the golden nematode of potatoes: *A*, Surface view in region of vulva and anus, showing pattern; *B*, deep focus of same region, showing fibrous layer; *C*, midregion of body, showing pattern and punctation; *D*, deep focus in the same region, showing punctation and fibrous layer. All photographs with phase microscope.

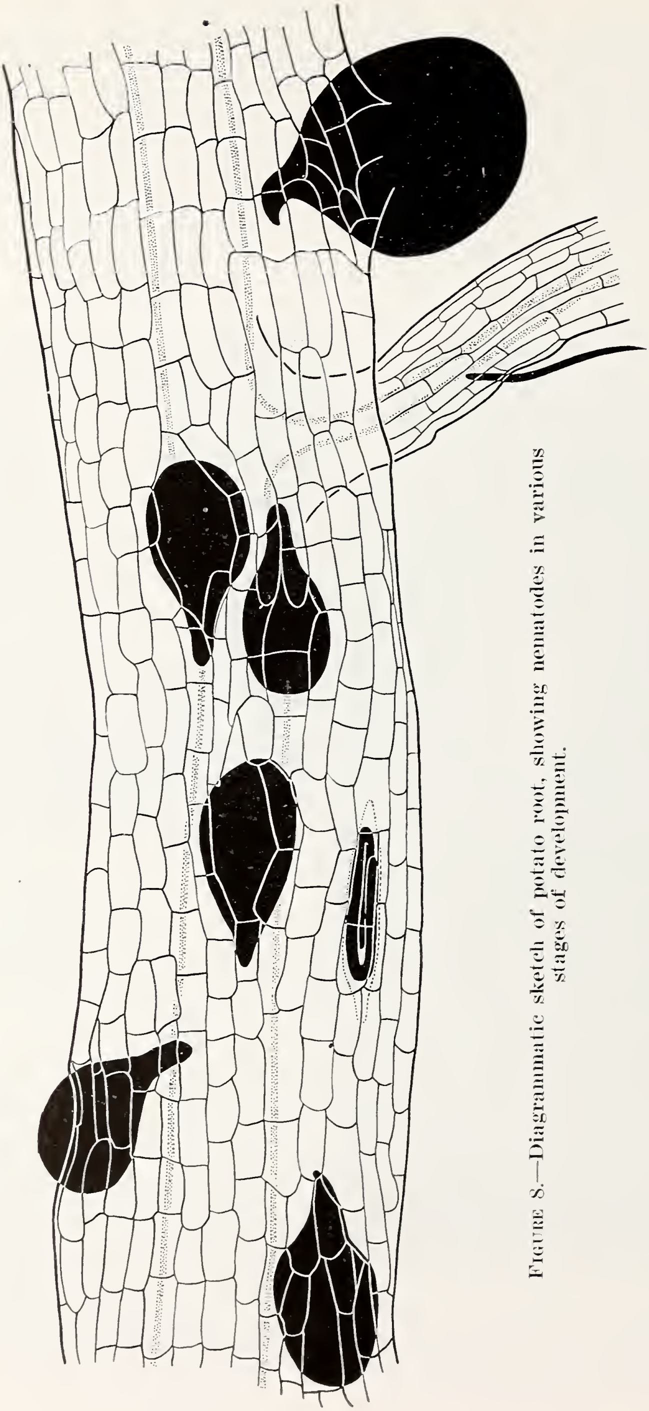

FIGURE 8.—Diagrammatic sketch of potato root, showing nematodes in various stages of development.

average of 114 females per gram of root plant showed no above-ground evidence of attack (fig. 9, *B*); plants with an average of 219 females per gram of root showed little evidence; and plants with 588 females per gram of root showed lack of thriftiness, particularly in bush development. Plants with 2.5 females per gram of root could hardly be distinguished from plants with 114. While no early potatoes such as Irish Cobbler were included in this experiment, previous experience has indicated there would have been practically no symptoms on this variety, even with an extremely heavy infestation during the growing season described.

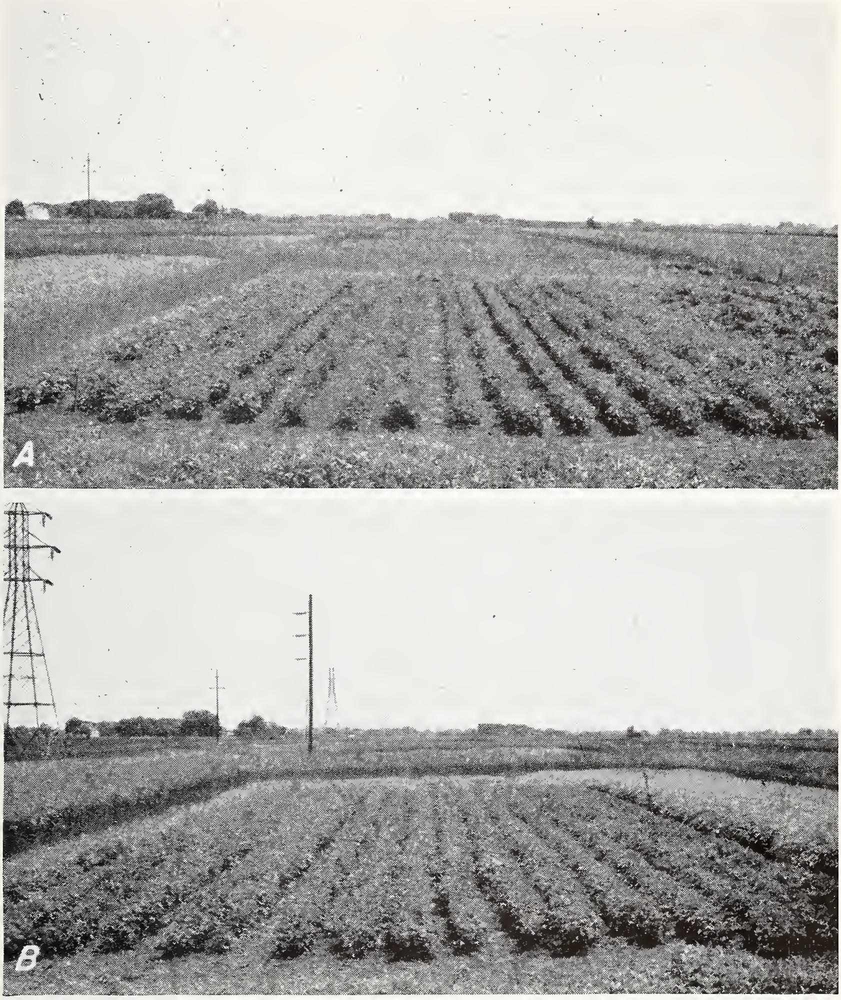

FIGURE 9.—Golden nematode-infested field plots of Green Mountain potatoes, 1946: *A*, Soil not fumigated, four center rows with no crop rotation and remaining rows in rye during previous year; *B*, soil fumigated previous fall, no crop rotation.

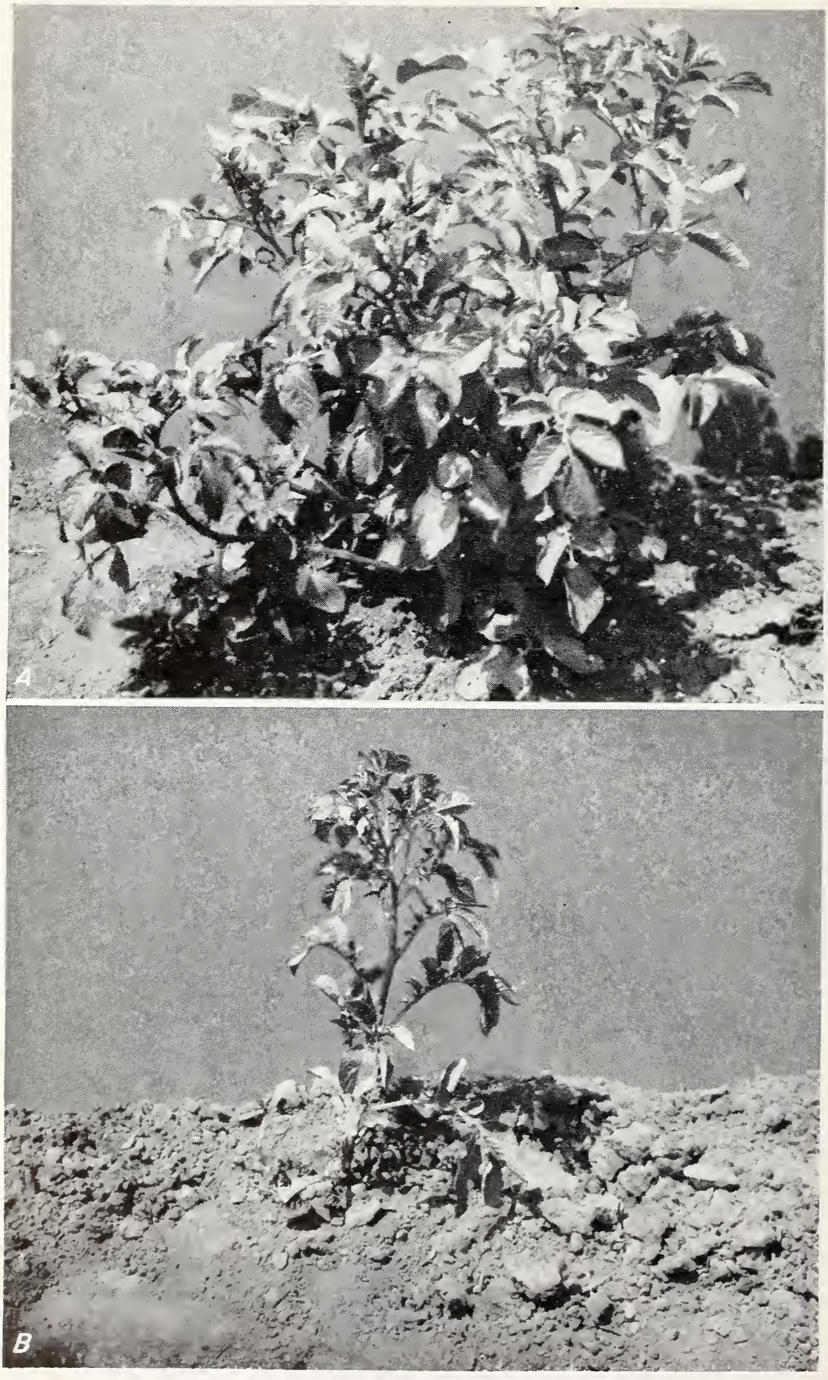

FIGURE 10.—Green Mountain potato: *A*, Normal plant; *B*, plant heavily infected with the golden nematode.

During a poor potato year, characterized by cold weather immediately followed by summer temperatures (no extended period between 50° and 60° F.), potato plants of late varieties having 250 or more females per gram of root have shown stunting. In a poor potato year, characterized by late-season dryness, plants of late varieties having 500 females per gram of root have shown premature death.

Host Range

This nematode is known primarily as a parasite of potatoes, for it is commonly responsible for 25 to 50 percent reductions in crops where heavy infestations occur. Cases have been reported where the crop reduction amounted to 90 percent.

In England this nematode has also been reported as responsible for crop losses in tomatoes. These cases have been chiefly in greenhouses supplied with soil from infested potato fields. While all varieties of tomatoes experimentally tested in this country have been found to be susceptible, nematode production on the roots is hardly comparable to that on potatoes (Mai and Lownsbery (*41*)) and it appears doubtful that tomatoes would maintain, over a period of years, the high nematode concentrations found in potato soils. Nevertheless the tomato does serve to propagate the nematode to a limited extent, and therefore it is not recommended in a crop-rotation scheme.

No other commercial crops are known to be parasitized by this organism (*41*). Other hosts known to occur in the United States are *Solanum dulcamara* and *S. sarachoides*. Neither of these has been found infected in this country under natural conditions.

Root Leachings

O'Brien and Prentice (*48*) found that hatching of eggs and emigration of larvae from cysts could be stimulated by exposure of cysts to water that had been percolated through pots of soil containing growing potato roots. Triffitt (*57*) recorded minor hatching in tap water as compared to such potato-root leachings. In general, workers have found that bacterial action destroys the active principle in root leachings, while filtering and heating to the boiling point cause no injury. Percolation of water through soil without plant roots has no stimulating effect. The active principle is apparently confined to the root tips. Such discoveries opened an entirely new line of investigation, leading to better selection of rotation crops and means of determining the nematode potential of soils.

Franklin (*30*) found that 1- to 8-year-old cysts produced active larvae on exposure to potato leachings and that 1-year-old cysts were much more potent than older cysts, hence much more damaging to crops. Further investigations in Great Britain by Triffitt (*58*) have shown that root leachings of other plants, including tomato, meadow grasses (*Poa trivialis* L. and *P. pratensis* L.), corn, and to a lesser extent lupines, barley, oats, wheat, and rye, also contain the hatching factor. Franklin (*28*) found 1-year crop rotation with corn highly effective in reducing the golden nematode damage to potatoes. Nonsolanaceous plants do not act as hosts for the nematode, and thus far no one has recorded golden nematode invasion of their roots even though they produce stimulatory materials.

Cysts that have not overwintered respond very weakly to the hatching factor; cysts that have overwintered will not respond if the temperature is too low. Ellenby (*23*) found that all eggs in a cyst do not hatch at once when exposed to the hatching factor. However, he found if such cysts are returned to tap water, then reexposed, further hatching and emigration from the cyst take place. It is therefore presumed that some metabolic products of the nematode tend to inhibit continuous emigration of the larvae from the cyst. Cysts exposed to the hatching factor in a range of buffered solutions were found to exhibit no hatching at pH 3.4, slight hatching at pH 4.0 and 8.0, and maximum hatching at pH 6.0.

Todd and associates (*56*) found that a season's leachings from 150,000 tomato plants when adsorbed on charcoal produced 140 grams of crude solid containing 1 to 2 percent of the active principle eclepic acid. This substance is unstable in alkalis and contains acetic, lactone, hydroxyl, and ethereal groups with one unsaturated linkage. It has also been termed anhydrotetronic acid (*42*).

Morgan (*46*), Triffitt (*57*), and Goffart (*34*) found that root leachings from mustards inhibit hatching of golden nematode larvae. Ellenby (*20, 21*) determined that the active principle involved in this case is allyl isothiocyanate and reports that this chemical has been used with some success in the control of golden nematodes in the field.

Nature of the Cyst

The remarkable longevity of this nematode appears to be connected in some way with the tough leathery cysts that are capable of persistence in soils for an undetermined number of years. At the fourth molt the new cuticle of the adult female is clearly more thickened than the cuticle of other stages. As the adult female further matures on the root the cuticle becomes more and more thickened and gradually turns color from white to gold and finally to red brown. Young, white to yellowish females removed from roots and dried have not been found to provide effective inoculum. Perhaps some physiological change in the cyst wall is necessary for the protection of the larvae. White females washed from the roots and dried in daylight turn yellowish almost immediately; this color change appears to be a simple oxidation phenomenon.

Ellenby (*24*) states that the oxidation is due to polyphenol oxidase. White cysts will oxidize catechol and tyrosine, and the action of the enzyme can be inhibited by carbon monoxide, hydrogen sulfide, potassium cyanide, potassium ethyl xanthate, and sodium diethyl carbamate, substances that are known to inhibit polyphenol oxidase. The last two substances react with the copper in the enzyme, and it is possible to reverse the inhibition by adding cupric chloride. Addition of benzoquinone causes the cysts to turn brown even in the presence of carbon monoxide. Polyphenols in the cyst wall were demonstrated by ammoniacal silver hydroxide. Permeability of the cyst wall to water was demonstrated as follows: The vulvar region of a cyst was coated with rubber solution and a fine capillary tube was inserted in the neck. Loss of water through the cyst wall was demonstrated by the lowering of the water level in the tube. A large cyst with a diameter of 0.6 mm. was found to contain 0.11 mm.^{3} of water and to lose this much in 15 minutes. The rate of water loss was reduced with time, and the cyst was unable to take in water so readily as it was lost.

Although Ellenby was unable to demonstrate the existence of sterol-like substances in the cyst wall, circumstantial evidence indicates that a chemical with many of the physical properties of a sterol is present. For example, water-repellency is demonstrated in ordinarily matured cysts, which float in water. New females, on the other hand, sink, unless dried momentarily; thereafter they also float temporarily but sink if deliberately submerged. Further, wetting agents remove whatever waterproofing substance there is present on old cysts when exposed over a prolonged period; thereafter, cysts sink and remain sunk. Boiling has the same effect.

The hard structures of the cuticle of several nematodes were shown by Chitwood (*11*, *12*) to consist of various layers of scleroproteins, which gave physical and chemical reactions of keratins, elastins, collagens, and mucoids. The eggshell proper reacts as a chitinoid. It seems possible that the materials termed polyphenols by Ellenby are a modification or substitute for comparable materials in other nematodes and may partially explain the remarkable durability of cyst-forming heteroderas.

In general, skeletoid structures are not the most important protective agents from the standpoint of membrane permeability. In addition to the so-called hard parts, other materials are found, either as infiltrations of particular layers or as delicate membranes. These substances behave as sterols or waxes. Von Brand and Winkeljohn (*6*) found ascaryl alcohol, cholesterol, and other waxy substances in nematodes. It appears possible that the waxy substance varies with the species examined. In the golden nematode the cyst wall is completely soluble in 10 percent sodium hydroxide, while the eggshell is not. The latter is probably chitinoid. The vitelline membrane behaves as a wax. The cyst wall is composed of several layers, most readily distinguished during the process of dissolving in sodium hypochlorite. Rigid structures in this wall are probably scleroproteins infiltrated with other substances governing permeability.

The contents of old cysts, after storage in an air-dry condition for 2 years, appear dead, but upon immersion in water the eggs and larvae of these old cysts revive after a few hours of soaking. Eggs and larvae of current females, however, taken from potato roots before they have changed color, then treated in this manner, give every evidence of death. Thus, we presume there is an increase in the protective mechanism of the nematode that occurs sometime between the white-female stage and the 8-month-old cyst. Freezing in soil ice, even alternate freezing and thawing, did not cause total mortality of cyst contents but did seem to cause minor mortality.

Infection of potato plants could be produced at every month of the year by using cysts 8 months old or older, provided the plants were grown at a temperature permitting nematode activity.

Temperature Relations

Several workers have made tests to determine lethal temperatures under various conditions. Triffitt and Hurst (*59*) exposed cysts of the golden nematode to various temperatures in water and subsequently exposed the cysts to potato-root extract. On the basis of these tests they concluded the following exposures were lethal: 130° F. for 5 minutes, 120° or 118° for 30 minutes, and 116° for 45 minutes. Engelmann (*25*) exposed infested soil to various temperatures and thereafter planted the soil with potatoes and indexed the roots for golden nematode infection. Sterilization of air-dry soil (containing 5-percent moisture) required 5 hours at 210° F., 10 hours at 198°, or 24 hours at 178°, while moist soil (15-percent moisture) required 5 hours at 158° F. or 10 hours at 140°.

Our records of the dissection of cysts previously immersed in water for 1, 2, and 5 minutes, in temperatures from 125° to 150° F., indicated mortality in 1 minute at 150°, 2 minutes at 145°, or 5 minutes at 130°.

In four replications of cysts exposed at 130° F. for 5 minutes in wire-gauze containers and subsequently used as inoculum for potato plants, one new female was produced on the roots, while a mean of 143 new females per plant was observed on potato roots grown with corresponding numbers of untreated cysts.

The wetness of the cysts at the time of exposure is a major item in determining the time and temperature required to kill. After exposure of cysts in moist soil for 3 months at 118° F., 6 percent (3 in 53) of the cysts still contained viable contents, while similar soil exposed to temperatures of 110° and 67° F. for the same period showed 29 percent (11 in 43) and 33 percent (11 in 35), respectively, with viable contents. On this basis the exposure at 118° caused an 87-percent reduction in viable cysts. Subsequently, potatoes were planted in this soil and raised at normal temperatures (about 65°). The mean number of females per plant as based on 8 replications was 134, 1,959, and 2,372 for the soil previously exposed at 118°, 110°, and 67°, respectively. Apparently there was no difference between infestations following 110° and 67°, but there was a clear reduction following 118° F.

Field records have indicated that a mean weekly soil temperature of 60° F. is necessary for swarming of the nematode larvae and consequent mass invasion of potato roots. Potato plants grown in constant temperature equipment with heavily infested soil showed no evidence of invasion at 53°, 56°, and 84° F. but were heavily infected at 67°. Differences in nematode injury associated with varieties, seasons, and planting dates can be better understood if the temperature relationship is known.

Varietal Susceptibility[3]

Carroll and McMahon (*9*) first called attention to varietal differences in crop reduction as a result of the golden nematode. They expressed the view that early varieties escape injury chiefly because they make better root growth at low temperatures in the springtime before nematodes become active. Chitwood and Buhrer (*15*, *16*) have verified this claim regarding American varieties. Thus, the variety Irish Cobbler makes substantial root growth at weekly mean temperatures of 50° to 55° F. and thereby escapes much of the injury encountered by the Green Mountain variety, which makes minor root growth at 54° F. and major root growth at 59°.

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[3] F. S. Gordon supplied the information presented under this heading. The work was conducted cooperatively with the U. S. Department of Agriculture while he was a graduate student at Cornell University, attached to the Nassau County agricultural agent's office.

Gemmell (*33*) found that certain British potato varieties produced fewer and smaller cysts and fewer larvae within the cysts than did other varieties. Ellenby (*22*) substantiated this work and extended it to South American tuber-forming solanums. Among these he found one or two species on which no cysts were formed. There is some possibility of developing a commercial potato that is immune to the golden nematode, but this will undoubtedly require many years.

In 1944 Gordon reported that there was a definite indication that the early varieties Warba, Irish Cobbler, and Chippewa gave significantly higher yields on heavily infested soil than the later maturing varieties Sequoia, Green Mountain, Sebago, Pontiac, Katahdin, and Houma (table 2). There were no significant differences between yields of the nine varieties of controls planted in the uninfested soil on the same date. Varieties, such as Irish Cobbler, that are capable of making considerable growth in cool spring weather possibly owe their greater yield in infested soil to their establishment before nematode invasion, rather than to any resistance on the part of the host. (See Chitwood, Clement, and Gordon (*17*).) Late varieties, such as Green Mountain, that grow less in cool weather are probably damaged to a greater extent because the nematodes invade the roots before the plant is well established. Unfortunately, the "clean," "light," and "heavily infested" records in table 2 represent separate fields.

TABLE 2.—*Yield of 9 varieties of potatoes grown on soil with and without golden nematode infestation, planted April 28–30, 1943*

Variety	Yield per acre in—		
	Clean soil [1]	Light to moderately infested soil [2]	Heavily infested soil [3]
	Pounds	*Pounds*	*Pounds*
Warba	16, 385	15, 826	7, 654
Chippewa	15, 950	11, 035	6, 192
Irish Cobbler	13, 630	16, 530	5, 848
Green Mountain	15, 805	10, 744	4, 988
Sequoia	15, 370	8, 857	5, 074
Sebago	15, 080	8, 276	4, 558
Houma	14, 790	9, 728	3, 096
Pontiac	14, 790	10, 164	4, 214
Katahdin	13, 920	7, 405	3, 268

[1] No significant differences (5 replications).
[2] Least significant difference at 5-percent level, 3,480 pounds; at 1-percent level, 4,857 pounds (5 replications).
[3] Least significant difference at 5-percent level, 493 pounds; at 1-percent level, 654 pounds (14 replications).

Varieties and planting date should not be considered separately. Observation in the field has shown that late-planted potatoes of any variety are more severely injured by the golden nematode than are early-planted potatoes. This point is corroborated by the figures given in table 3 for the Irish Cobbler variety planted at different dates in infested soil.

There is no significant difference between the yields of potatoes planted on the first three dates, but there is a significant difference between the yields from the plantings of these dates and the yield of those planted on May 15. While there is no definite proof that the lower yields of the later planting were due entirely to the activity of the nematode, it is indicated that on infested ground early planting was more favorable for higher yields.

TABLE 3.—*Yield of the Irish Cobbler variety of potato on golden nematode-infested soil according to planting date (5 replications), 1943*

Planting date	Mean temperatures after planting		Yield per acre	
	First week	Second week		
	° F.	*° F.*	*Pounds*	*Bushels*
Apr. 7	45	48	21, 489	390. 7
Apr. 15	48	50	20, 182	366. 9
May 1	58	58	19, 021	345. 8
May 15	59	65	12, 151	220. 9

SURVEY METHODS[4]

Field inspection for detection of the golden nematode may be conducted on the basis of either plant or soil sampling, each of these procedures having certain advantages and disadvantages. As a general policy, soil sampling is preferable in exploratory work when there is no previous history of infestation, as more samples can be inspected per man-hour. It may be conducted at any time of the year in which the ground is not frozen and regardless of crop.

Plant inspection, on the other hand, is to be recommended where there is reason to believe that the golden nematode is present or to confirm soil sampling. Plant inspection should be limited to the second month after weekly mean soil temperatures have reached or exceeded 60° F. It has been used to locate infested areas as small as 25 square feet in fields not previously known to be infested and loci as small as 3 square feet in fields where nematodes had been previously located by soil sampling. Root inspection also provides a convincing demonstration for educational purposes.

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[4] Improvements developed since 1947 are not included.

Plant Sampling

In sampling plants the best procedure to follow is to examine plants along lines contrary to rows, as infestation tends to follow the row. The plant, including the seed piece, is carefully lifted with a trowel, then turned over, and its roots are examined with the naked eye; the seed piece is removed and roots immediately beneath it are observed with special care, as nematodes are more apt to be present in this location than in any other place. For routine purposes, the inspectors of a field line up at 30- to 60-foot intervals (depending on how thorough an inspection is to be made), start from staggered positions, and travel cross-row. They take plants from every fifth or sixth row (according to plan), except at the edges of fields, around barns, and near roads, where the sampling is increased to every second row, because it is in such locations that the early infestations may be expected. Conversely, the sampling can be decreased to every tenth row in the middle of large fields.

In general, the inspector makes no deliberate selection of plants other than those that fit the plan. In other words, he does not seek individual poor plants, because an infestation of sufficient age to cause symptoms in one or two plants is usually so widespread that a find could hardly be avoided; rather, emphasis is laid on finding the nematodes before field symptoms are evident. In the course of an inspection, however, the inspector should look up and down rows and test any additional location where there is a group of plants showing poor development.

Upon making what he believes to be a find, the examiner should remain at that spot and signal his partner, who will then join him to confirm the evidence with a hand lens, and will place roots with nematodes in a vial of 10 percent commercial formalin. The partner then paces off two fixed points at right angles and enters the location on a map. As a rule it is wise to proceed from here with closer inspections on adjoining rows and in the same row, for initial finds commonly represent streamers from the true locus.

The advantages and limitations of survey by plant inspection are brought out in the following discussion. As the roots removed with a seed piece usually represent 40 pounds of soil and a root system is more readily examined than that quantity of soil, plant inspection is more highly effective than soil inspection for disclosing infestation at the particular point sampled, but fewer points can be sampled per man-day. As a routine matter a man can easily examine more than 200 plants per day, or the equivalent of 8,000 pounds of soil. Numbers of plants per acre according to various spacings of sampling can be determined. Thus, assuming that the potatoes are planted in 2½-foot rows, a man pulling plants in alternate rows at 30-foot intervals in the row would cover less than 1 acre per day. The other extreme in spacing—namely, every tenth row at 200-foot intervals—would permit inspection of 12½ acres per man-day, but only 8 locations per acre. The following tabulation gives the number of plants that can be sampled per acre, according to the sampling pattern.

Take samples from—	*Plants per acre*
Every 2d row at 30-foot intervals	294
Every 4th row at 30-foot intervals	147
Every 4th row at 60-foot intervals	72
Every 6th row at 60-foot intervals	48
Every 10th row at 60-foot intervals	29
Every 10th row at 100-foot intervals	17
Every 10th row at 200-foot intervals	8

Visual inspection of potato roots in the field presents a few hazards of misidentification. These are certain fungus spores, aphids, root-knot nematodes, and species of the genus *Heterodera* that may be present in the soil or on intertwined weed roots. Root-knot nematodes differ in that they always occur within swellings, but their egg masses may project externally and become yellowish to orange. The light reflection of such egg masses is less intense than that of the golden nematode and the egg mass merges with the root, whereas the body of the female golden nematode meets the root tissue at a sharp angle. It is well to make sure that any root with a suspicious specimen is actually attached to the potato plant.

Soil Sampling

The routine soil-sampling technique adopted by the Bureau of Entomology and Plant Quarantine consists of lifting small soil samples (about 20 grams per sample) at intervals of 8 paces in the row and 8 paces across rows. This gives about 100 samples or about 3 pounds per acre. Soil is collected in paper bags and properly labeled, each bag representing around 2 acres. Between 8 and 16 acres are thus sampled per man-day. Resampling in case of suspicious findings is done at intervals of 4 paces across rows and 4 paces in the row or 2 paces across rows and 2 paces in the row; these sampling patterns give 400 and 1,600 samples per acre, respectively.

Since light infestations are commonly less than 4 rows wide, the probability of finding small infestations is greatly enhanced by less sampling in the row and more sampling of rows. Thus a sampling design with 66-foot intervals in the row and 12-foot intervals across rows would result in the same number of samples per acre as 24- by 24-foot samplings, but would disclose lighter infestations. Likewise, staggered sampling would improve the design.

Assuming the distribution of cysts to be uniform throughout a field, with 2,500,000 pounds of soil in the top 8 inches of an acre, samples totaling 3 pounds per acre would require 833,333 cysts per acre in order that one would have a reasonable chance of finding one cyst in the soil from one particular acre. In a 100-acre field so examined, there would be a reasonable chance of finding one cyst in one 3-pound bag of soil if the field had a mean of 8,333 cysts per acre. As the distribution of cysts in lightly infested fields is never uniform but tends to occur in spots and streaks, it is exceedingly important that sampling be designed to produce the most effective results possible with a given amount of labor.

SOIL PROCESSING[5]

Soil is brought to the laboratory in the labeled paper bags and stored on drying racks (fig. 11) for 2 to 3 weeks, then washed and examined for golden nematode cysts. The drying process was introduced to overcome the tendency of full wet cysts to sink in water. Fenwick (*26*), Bainbridge (*3*), Morgan (*46*), and Powell (*51*) have described different methods for the recovery of cysts from soil. All of these depend, as does the method described herein, on the tendency of dry cysts to float. Methods described by Fenwick and Bainbridge depend on a continuous water flow; soil is placed in a deep stationary container, and cysts are floated off the top onto a screen. The present method is more rapid for the quantity of soil processed, will disclose lighter infestations, and permits more thorough rapid cleaning through the use of less complicated apparatus than methods described by other workers. It has the added advantage of being moderately satisfactory even for moist soil, since full cysts sink more slowly than sand, and quick pouring results in the collection of most of the cysts.

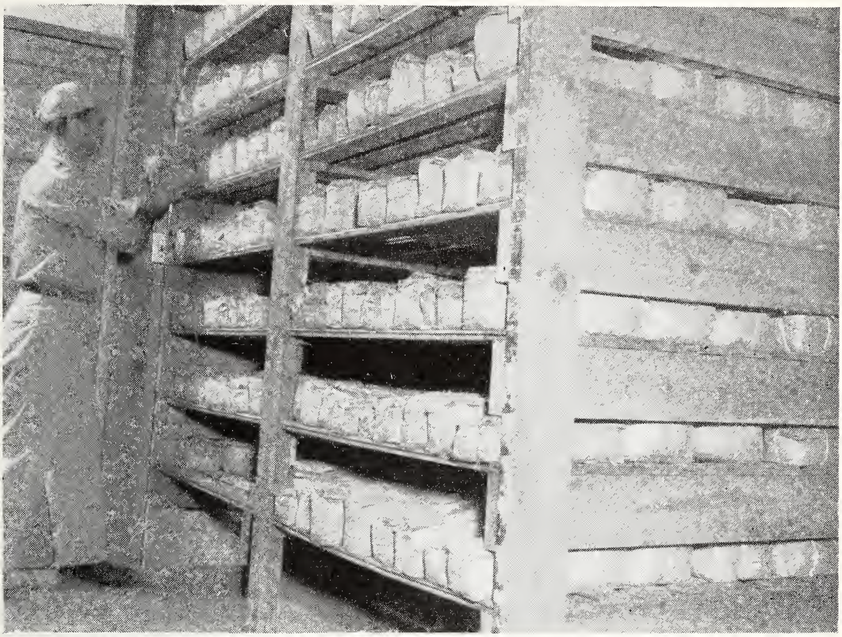

FIGURE 11.—Packaged soil samples on drying racks.

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[5] Processes described under this heading were worked out by J. H. Machmer, Division of Nematology, in cooperation with the Bureau of Entomology and Plant Quarantine.

WASHING

The soil from a bag (about 6 pounds, a sampling from 2 acres) is poured into a 12-quart white-enameled bucket and roiled vigorously with water. The supernatant fluid is poured into a second bucket (fig. 12), is allowed to settle momentarily, and is then poured simultaneously through 25- and 50-mesh copper screens (fig. 13). The nematologist is aware that some golden nematode cysts will pass through a 50-mesh screen, but the proportion is minor when compared with the additional amount of debris that would have to be examined if finer screens were used. The process is repeated until the residue in the buckets consists of only sand and gravel. The residue on the 25-mesh screen is thoroughly rinsed, and the rinsing water is caught in the 50-mesh screen. The residue on the 25-mesh screen is then discarded. The residue on the 50-mesh screen (fig. 14) is rinsed into a 600-cc. beaker, labeled as was the source bag. Material in the beaker is allowed to settle for about 30 minutes, the flotsam then collected on a 50-mesh screen, and the sediment discarded. The procedure of washing requires about 15 minutes per 6-pound bag of soil. If emergencies arise requiring quick determination of infestation, wet soil taken directly from the field may be processed by following the procedure given, but omitting the 30-minute delay for settling debris.

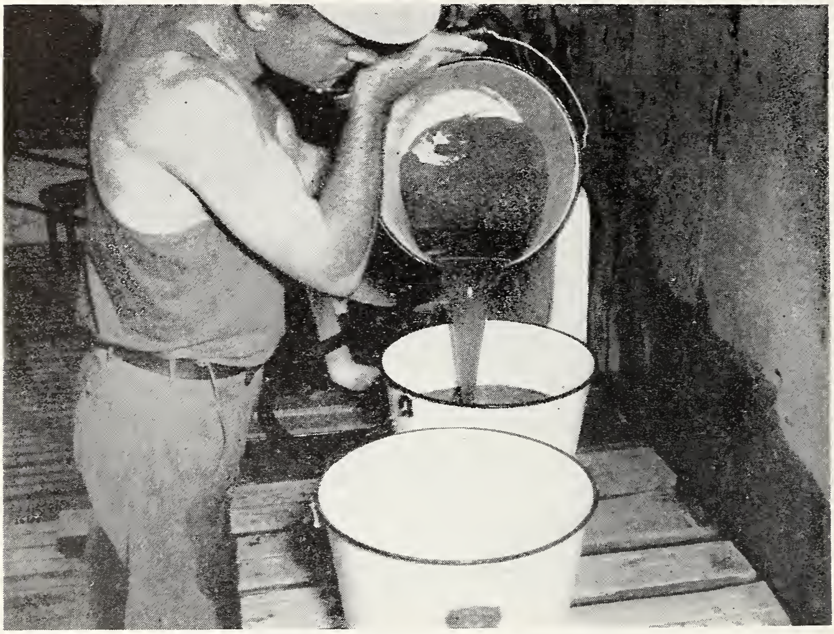

FIGURE 12.—Washing and decanting soil.

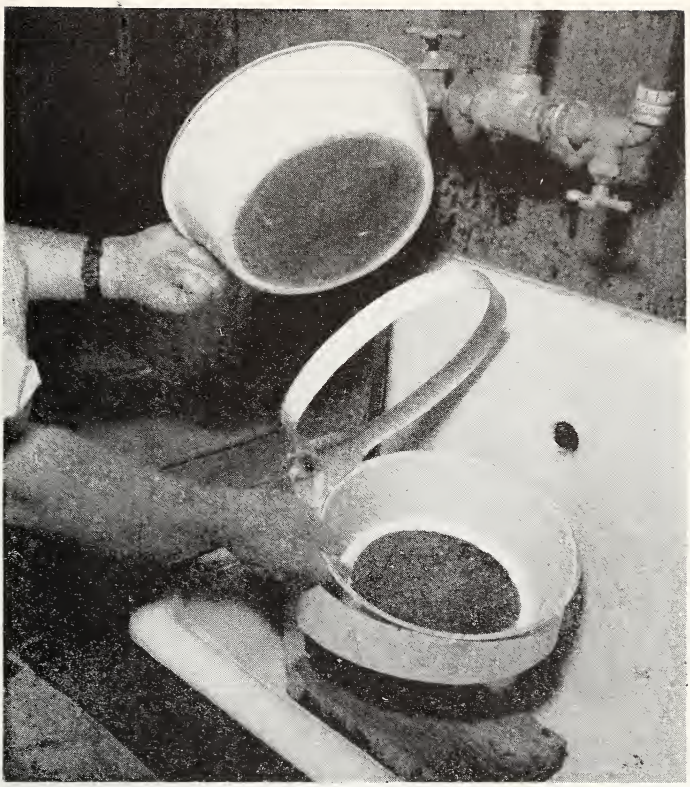

FIGURE 13.—Screens used for the collection of golden nematodes: Upper screen, 25-mesh; lower screen, 50-mesh.

EXAMINATION

Material collected from the beaker flotsam on a 50-mesh screen is divided into 20 to 50 small samples in as many syracuse dishes (fig. 15). Water is then added until the syracuse dishes are nearly full. Each syracuse dish is marked so that one can tell when the entire dish has been examined. Using a low power of the dissecting microscope and reflected light, the examiner looks at all materials gathered around the periphery of the dish (fig. 16), then the center of the surface, and finally the sediment. With practice, the examiner can distinguish golden nematode cysts by their color, relative size, shape, and texture. Any suspicious object is set aside, properly labeled, for final examination under a compound microscope. According to the amount of plant debris, the examiner may process washings from 150 to 300 pounds of soil per day.

CONFUSING ITEMS

Among the various organisms simulating the golden nematode of potatoes in soil samples are eggs of oligochaetes, tardigrades, and

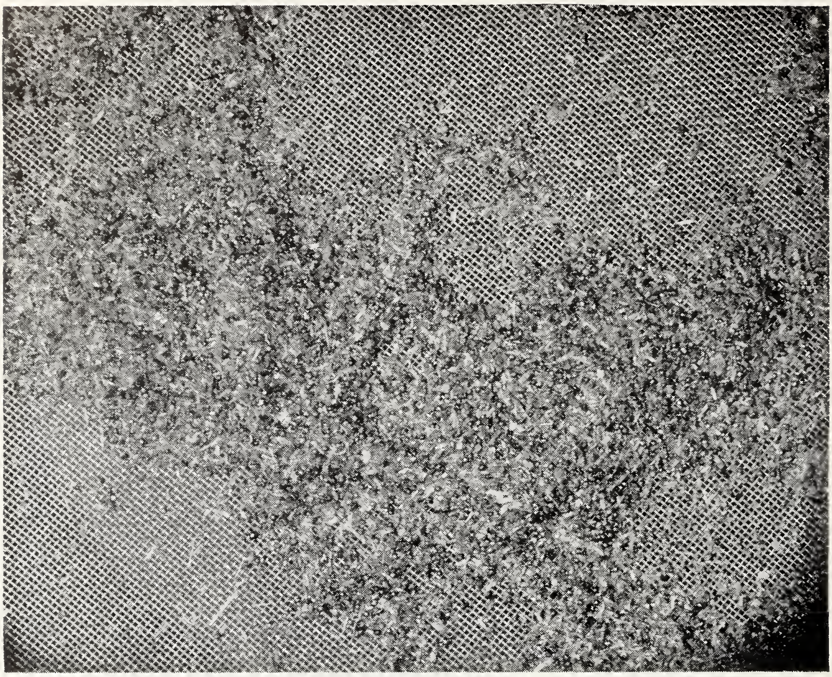

FIGURE 14.—Golden nematodes (cyst stage) mixed with debris on 50-mesh screen.

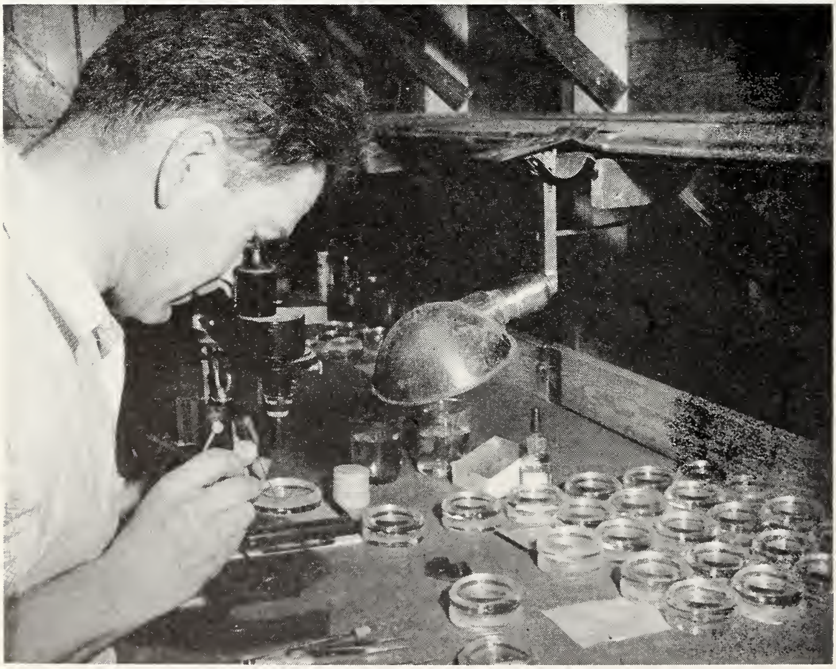

FIGURE 15.—Beaker flotsam in syracuse dishes for examination.

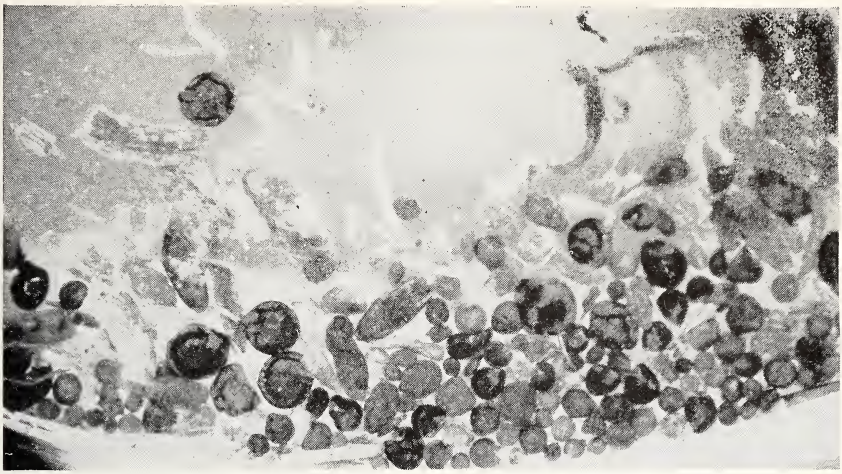

Figure 16.—Golden nematode cysts among weed seeds and roots, as the flotsam appears in a syracuse dish.

rotifers, and spores of fungi (sclerotia, chlamydospores, and *Endogone*), besides various other members of the genus *Heterodera.* Most of these eggs and spores have brittle walls, while *Heterodera* cysts are somewhat leathery. Cysts containing nematode eggs and larvae (fig. 17) among the cyst contents are sufficient grounds for suspicion on the part of the uninitiated. However, empty nematode cysts are

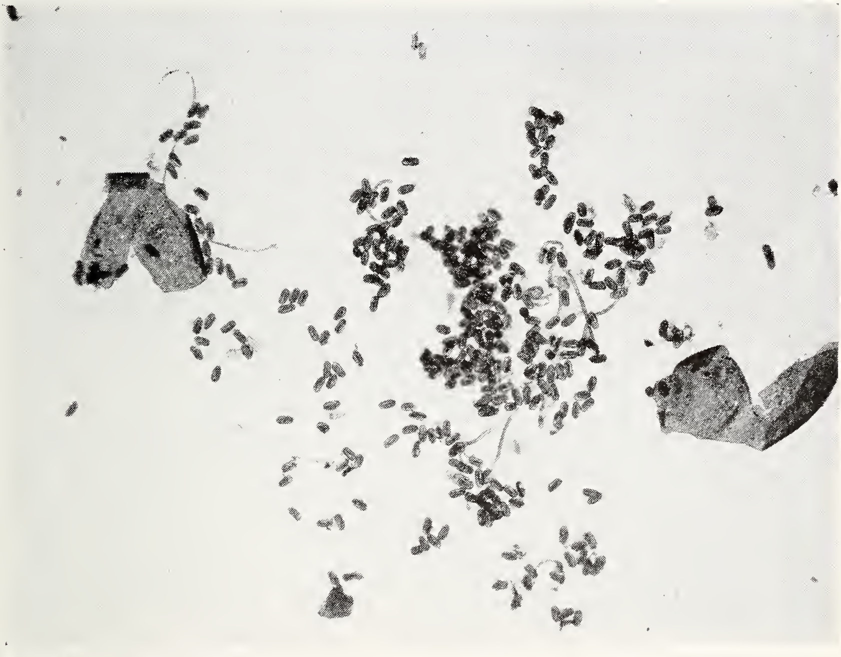

Figure 17.—The dissected cyst of a golden nematode, showing eggs, larvae, and remnants of the cyst wall.

more common than full cysts and are definitely identifiable on the basis of the cyst-wall pattern and relative size of vulva and anus. Specimens are dissected in lactophenol,[6] the posterior end of the cyst being mounted face-up, together with other parts of the cyst. The slide is then protected with cellophane and scotch tape, and mailed to the identifying unit in a slide holder. The cover slips of such mounts may be held fast by the use of a suitable ringing material (Clearcol, or lactophenol gum).

DISPERSAL OF THE DISEASE ORGANISM

Dispersal of the golden nematode must be classified under two major headings, local and distant. Factors that play a part in local distribution may have little or no bearing at long distance.

Local Dispersal

TOOLS AND IMPLEMENTS

Spread of the golden nematode within fields is chiefly in the direction of cultivation, though lateral spread also occurs. Tractors, plows, disks, and diggers seem to be the major factors of spread within fields, and of considerable importance from one field to another because of multiple-farm operation. Longitudinal spread of 400 feet in the direction of cultivation and contrary to water flow was observed in one season; this distance extended to 1,000 feet in the same instance in 4 years. Lateral spread of 96 feet was observed within a field in one season, becoming 300 feet in two seasons. In one instance an infested and an uninfested field were separated by a hedgerow. Owing to the shape of the field, rows in the infested field were not quite parallel to the hedgerow, so the farmer plowed through the hedge (at the end of his rows) in three places. Golden nematodes were observed on plants at these crossings and at no other places in the uninfested field. Hedgerows have now been largely destroyed in this area; farmers plant to the very edge of their properties, turning their equipment on roads or the adjoining farms wherever possible. In this manner there is considerable exchange of soil between adjoining fields. It is not unusual to find small infested spots 2 to 4 rows wide and 30 to 50 feet long, and farther along in one of the rows several additional smaller loci, plus, occasionally, a small locus situated 20 to 40 rows laterally. In one case an infestation was found 4 rows wide and 5,200 feet long. These results point definitely to the distribution of soil by farm implements.

Sometimes minor spots representing new infestations in fields may be found in nearly any location, without apparent reason until discussion with the farmer provides the key. In one instance the spot was located at the same place that a second-hand digger, purchased from the owner of an infested farm, was originally put in operation by the purchaser. In another case, the position was found to have been a loading station. The farmer had other infested fields nearby, and in planting, digging, and spraying operations he commonly employed the same truck to supply seed, fertilizer, sprays, and bags and to pick up bagged potatoes in the two fields at the same time. In still another case, 5 gallons of soil containing approximately 32,000 cysts were removed from a tractor after operation in an infested field. Farmers who operate 3 to 10 fields, sometimes as much as 15 miles apart, use the same farming equipment and trucks; at the present time regulations require therefore that equipment used on infested fields must be steam-cleaned before it may be used on uninfested fields.

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[6] Lactophenol = 46 cc. lactic acid, 60 cc. phenol, 96 cc. glycerine.

PICKING OPERATIONS

Although items used in picking operations, i. e., the cars, baskets, and bags used by potato pickers, can undoubtedly assist in dispersal within fields, these items may be ignored as dispersal factors, as the movement of soil by farm machinery is so much greater quantitatively. Between fields, however, picking operations constitute a relatively greater hazard. In wet weather it is common for a farmer to shift from one field to another when he finds the first field is too wet for digging operations and the second is higher and drier. Pickers park their cars in the fields and much mud and even whole potato plants can be attached to wheels and undercarriage. Pickers proceed on hands and knees; knee pads, if not picking clothes, are used throughout the season. For example, 8 cysts were found in a single nail hole of a boot used in an infested field and 180 cysts were found in the dirt on the floor where a worker removed his shoes after a day in the field. The same baskets and bags are used for harvesting over a period of years, until they wear out, and the dirt picked up in them from infested fields unquestionably may be dropped off or emptied out in other fields. For example, dirt from pick-up bags selected at random showed 37 cysts per 10 grams of soil.

MOVEMENT OF POTATOES AND DEBRIS

A farmer operating several fields, often widely separated, usually maintains a central location on his home farm for grading and packing potatoes. Thus, potatoes from infested fields carry nematodes direct or in adherent soil to these locations. A record of the events leading to final discovery of the golden nematode on one farm involved in such a central location is as follows: In 1942 and 1943, this home farm was inspected and no golden nematodes were found, but in the fall of 1943 the farmer brought potatoes from a heavily infested field to his home farm for grading at his barn. Debris under the grader was found to contain six cysts per 10 grams of soil. In 1944 he planted the infested field to turnips because of the heavy potato-crop losses of the previous year. Then he buried turnips from this field behind his barn. It was not until 1946 that inspection proved his home farm was infested.

Debris from grading operations, potatoes too small for market, and like waste materials have been spread to fields adjoining the central grading point, thus bringing the pest from infested fields some miles distant. In one such case a field was found to have two small loci of infestation in 1942. The farmer, who had rented this land only 1 year previously, did not renew his lease in 1943. However, he had graded the crop from the infested land on his own farm, 3 miles distant, and scattered the debris on his fields. Repeated inspection failed to disclose the disease on his home farm until 1948.

The stalks and roots of plants from infested fields have been dumped in valleys through which water drains to other, noninfested fields, and have thus effected a spread.

FLOODWATER

Since the nematode cysts float, floodwaters are a continuing hazard. In one case the evidence indicated that the infestation was carried 850 feet in a single season by floodwaters. Much of the potato land of Nassau County is without well-marked surface drainage, and fields and highways have at times become converted into lakes and rivers. This is most apt to occur in the springtime when the ground is frozen at depths of 6 to 8 inches and thaws when it rains. However, since full cysts tend to sink more readily than empty cysts, this means of dissemination is not so important as by other means.

DUST STORMS

Dust storms are common in the farming area of Nassau County and may account for new loci of infestation from time to time. In some preliminary tests, traps set at 5 feet above a heavily infested field were found to contain a few cysts, but none of those examined showed viability. After one dust storm, when much of the ground was covered by snow, collections were made of the dirt in the snow on top of uninfested lands. At a point 570 feet distant from a heavily infested field, 115 grams of debris in the snow contained 78 cysts, 3 of which were viable;[7] at 660 feet, 135 grams of soil contained 83 cysts, 11 of which were viable; at 935 feet, 14 grams of soil contained 1 viable cyst; and at 1,300 feet, 10 grams of soil contained no cysts. Soil of the heavily infested field contained approximately 2 cysts per gram; the cysts were about 20 percent viable.

SEED POTATOES

Although many farmers on Long Island formerly raised second-crop potatoes for seed, this means of local dispersal has apparently been a minor factor. Only one infestation has been traced to this source. In this case potatoes grown locally were used on the field in 1942 and a small locus of infestation was found the following season.

Distant Dispersal

SEED POTATOES

Most European countries have banned the use of potatoes from golden nematode-infested land for seed purposes. Thus far Great Britain has not done so. As newly dug potatoes from heavily infested land bear large numbers of nematodes, New York State regulations have banned the sale of potatoes from infested or exposed lands for seed purposes. Martin (*43*) reported the discovery of viable golden nematode cysts in soil adherent to seed potatoes imported into Southern Rhodesia from Scotland. The potatoes originated from a field in which potatoes had not been grown for 11 years immediately prior to the crop in question.

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[7] For the sake of brevity the terms "viable cysts" or "nonviable cysts" will be used, rather than the accurate term "cysts with viable (or nonviable) contents."

TABLE STOCK

Machmer (*40*) reported the finding of 379,500 golden nematode cysts per carload (300 bags) of freshly dug potatoes as prepared for shipping. Soil washed from such tubers contained 3,552 cysts in 122 grams (dry weight), or 29 cysts per gram, although the soil in the field from which these tubers originated contained only 2 cysts per gram. No check was made on the viability of these cysts. Grading and brushing dislodge a large part of the adherent soil and most of the nematodes except those situated within the eye of the potato. Potatoes from the same field from which Machmer's observations were made, after several handlings and storage for 6 months, showed no cysts attached in several hundred examined. Certainly the majority of the cysts become dislodged in storage. For this reason soil and debris in the bottom of bags is considered more dangerous than the tubers themselves.

Leiper (*39*) reports on the dangers connected with soil and debris from second-hand potato barrels. It would seem that in England potatoes are commonly marketed in barrels, the tops and stalks being added as packing material. Leiper reports as many as 1,200 cysts attached to the roots of a single potato stalk used for packing. After potatoes are sold from a barrel the retailer sells the barrels to farmers, who dump the debris on their fields. One could not design a more efficient means of dispersal of the pest. New York State quarantines restrict the sale of potatoes from infested lands for consumption in the city of New York and to processing factories such as alcohol, starch, and chip plants.

RE-USE OF SECOND-HAND BAGS

Burlap bags generally used for the marketing of potatoes are sold by the potato retailer to bag dealers who clean the bags and resell them. Because the debris in these bags is a particularly potent source of nematodes, New York State has permitted the packaging of potatoes from infested soil only in disposable paper bags.

TOOLS AND IMPLEMENTS

Growers in the New York infested area have been expanding their operations to other, some of which are distant, counties within the State, and to other States as well. Some shipped tractors and various farm tools to these new points before regulations were enacted. However, repeated inspections have so far failed to establish the presence of the organism in these areas. At the present time, such equipment must be cleaned (fig. 18) under supervision before a permit is issued for its movement.

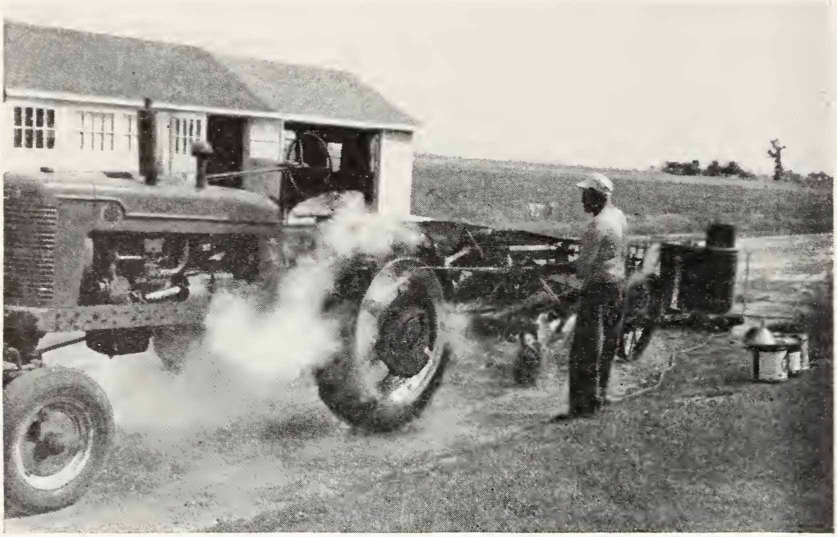

FIGURE 18.—Steam cleaning of equipment, as required by New York State Department of Agriculture and Markets.

SOIL MOVEMENT

Soil about the roots of nursery stock and soil accompanying bulbs and similar materials appear to be the major source of introduction of *Heterodera* spp. from foreign countries.

NATURE OF POPULATIONS

SOIL PROFILE

The nematode population is distributed in the soil in direct relation to the quantity of growing potato roots. O'Brien and Prentice (*48*) reported finding cysts at depths of 28 to 36 inches in a deep sandy loam, while Chitwood and Feldmesser (*18*) found cysts a rarity at 17 inches in black Hempstead loam. In the latter instance (fig. 19) a plow sole of yellow clay at 9 inches stopped deeper root penetration. Table 4 shows the correlation between root weight and nematode population in various soil sections. This particular potato plant was estimated to have produced 31,300 new cysts on its roots. Old cysts in the soil occupied by this plant were estimated to number 277,000.

FIELD RECORDS OF POPULATION INCREASE

Johnson and Thompson (*37*) found that the increase in number of new viable cysts per 10 grams of soil was greatest in the most lightly infested soils and smallest in the most heavily infested soils. Crop damage was noted when the population before planting reached 4 viable cysts per 10 grams of soil. Chitwood and Feldmesser (*18*) verified these observations, even to the extent of finding a net reduc-

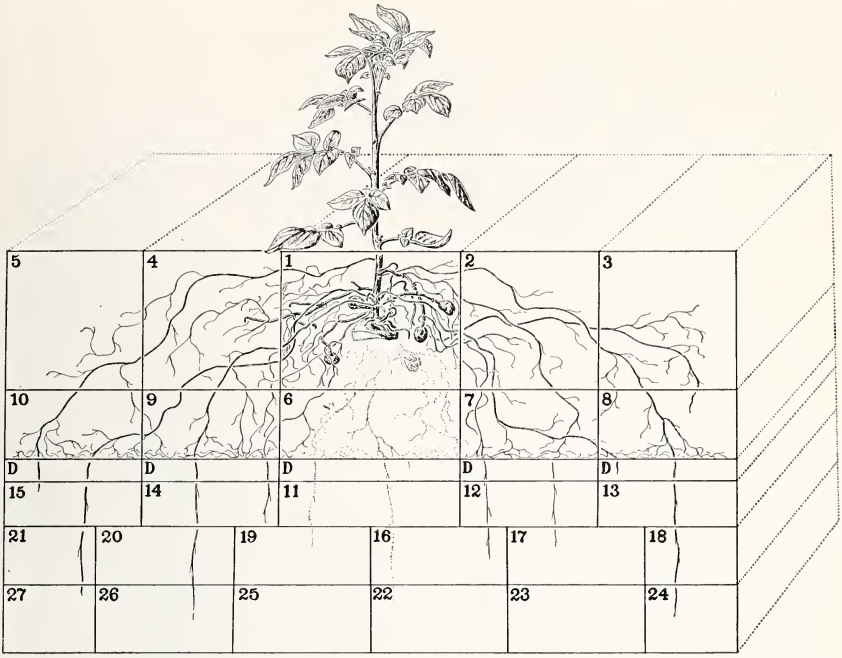

FIGURE 19.—Diagrammatic representation of heavily infected five-tuber potato plant, showing distribution of roots; soil blocks are numbered. The layer represented by *D* was hardpan and was not examined.

TABLE 4.—*Distribution of golden nematode females and cysts in the soil occupied by a single potato plant*

Section No. [1]	Old cysts per 10 grams of soil	New females per 10 grams of soil	Total root weight	New females per gram of root
	Number	*Number*	*Grams*	*Number*
1	40. 990	10. 662	25. 3	809
2 and 4	43. 686	2. 025	3. 19	919
3 and 5	37. 030	1. 656	1. 86	931
6	11. 165	. 387	. 31	916
7 and 9	6. 806	. 782	2. 73	157
8 and 10	5. 400	. 316	. 32	541
11	. 251	0	(2)	
12 and 14	. 363	. 003	(2)	
13 and 15	. 110	0	(2)	
16 and 19	. 074	. 004	(2)	
17, 18, 20, and 21	. 017	0	(2)	
22 and 25	. 004	0	(2)	
23, 24, 26, and 27	. 006	. 002	(2)	

[1] See fig. 19.

(2) Trace.

tion in the number of viable cysts per unit of soil in extremely heavy infestations (table 5). Although individual field records of cyst counts have at times indicated a per annum rate of reproduction as high as 60 times, the mean observed increase in cyst count, before crop damage has been observed, is 7.1 times.

Table 5.—*Numbers of viable cysts per 10 grams of soil immediately before and after a potato crop* [1]

Plots	Cysts per 10 grams of soil—		Ratio of increase or decrease
	Before cropping	After cropping	
C1 and C6	9. 38	6. 48	0. 69
C2, C4, C7, and C8	3. 79	6. 23	1. 64
C3	. 91	5. 31	5. 84
C5, C9, and C10	. 11	. 83	7. 54

[1] Plots were ½ acre each. Figures are based on 5 to 6 pounds of soil taken from 24 locations in each plot.

Greenhouse Pot Records of Population Increase

Carroll (*8*), Carroll and McMahon (*9*, *10*), and Chitwood and Feldmesser (*18*) have conducted tests in pots, using known quantities of inoculum. Chitwood and Feldmesser found that the increase in the total number of new females produced on a potato plant dropped sharply when the number of new females per gram of root reached 576, and a minor decline in potato production was noted at the same level. The maximum number of new females produced on a potato plant was reached when the number of new females per gram of root was 751. Greater quantities of inoculum produced no further increase in the total number of new females per plant, but the number per gram of root continued to increase. At 926 new females per gram of root, crop reduction was significant, while at 1,231 new females per gram of root both crop and root weight were significantly reduced. These facts clearly demonstrate the mechanism of crop damage due to the golden nematode and the mechanism by which populations become static.

Relation of Population to Crop Damage

Crop damage is caused by mass invasions of nematodes that kill the roots. Death of roots causes death of any nematodes contained therein. In a good crop year a plant makes better root growth and the nematodes attacking its roots are less concentrated, hence kill fewer roots, than in a poor crop year. In addition, the plant produces a better crop with a given amount of root system when there is adequate water. Such conditions tend to permit an exceedingly large nematode population build-up. If poor growing conditions occur during the following year, such a nematode population may constitute a surplus, i. e., more than the plants can maintain. If this is the case, large quantities of roots are killed, the plant is stunted or dies from lack of water and food, and the nematode population is reduced. Optimum growing conditions will again produce a surplus of nematodes. Thus a population tends to level off at around 5 or 6 viable cysts per 10 grams of soil. When the population increases to 8 to 12 viable cysts per 10 grams of soil as a result of unusually favorable growing conditions, crop damage is so extreme as to cause reduction of the nematode population.

RELATION OF DISEASE TO SOILS AND FERTILIZER

Much has been written concerning the prevalence of the golden nematode of potatoes in various soils, and the European consensus is that the nematodes are especially injurious in sandy soils. Boyd (*5*) inoculated various types of soil with a known number of larvae and planted the soil to potatoes. He found that five times as many new cysts formed on potatoes grown in sand than on those grown in clay. Carroll and McMahon (*9*, *10*) found golden nematodes in all types of soils of Ireland, even in a peat bog. On Long Island the central infestation is on a heavy dark organic soil, termed Hempstead loam. This soil contains considerable clay. Infestation has also been found in light sandy loam in other Long Island locations.

Peters (*49*) thought that soil acidity had some influence on the nematode populations, but O'Brien and Prentice (*48*) found no relation between cyst count and pH between 4.2 and 6.3. They did feel that crop injury was less marked in areas where the pH range was 4.2 to 5.0. Carroll (*8*) found severe nematode infestations in soils from pH 7.2 to 7.8. Since the pH range for sound potato culture is between 4.8 and 6.8, the nematodes appear well adapted to the pH range of potato soil.

Manure dressings have been generally recommended for potato-sick soils. Miles (*44*) and Miles, Henderson, and Miles (*45*) obtained increased potato yields with manure in combination with artificial fertilizer up to twice as great as the yields with artificial fertilizer alone. However, the nematode production was increased proportionately, and presumably such practice would merely raise the nematode concentration required for injury.

CONTROL

Control measures for the golden nematode may be designed to permit the growing of satisfactory potato crops with the minimum possible disturbance of routine crop production. Or they may be designed to limit the spread of the nematodes by every practical means without regard to crop production. In countries where the golden nematode is generally distributed, it is too late even to consider the latter method. Methods such as those discussed below must be used, even though they involve heavy expense or prevent the use of infested soil for potato production oftener than 1 year out of 3 at most. Where the golden nematode is confined to one small portion of the country, as in the United States, it seems preferable to attempt to keep it confined rather than to risk contamination of soil in other parts of the country and the expense and trouble that would follow as a consequence.

Crop Rotation

In the early stages of a golden nematode infestation, 2-, 3-, or 4-year crop rotation is adequate for the production of a normal crop of potatoes. According to European workers, when the infestation becomes older and better established, 5-, 6-, or 7-year crop rotation has been found necessary to gain the same end.

An understanding of the mechanism of control by crop rotation is necessary in order to plan such a course intelligently. At some stage in their life histories most nematodes may remain dormant, i. e., inactive, requiring neither host nor other source of food. For practical purposes, we may think of this period as one of suspended animation. In the case of the golden nematode of potatoes, this is the egg stage contained within the body wall of the dead mother, which forms a remarkably tough and effective protective coat. Under favorable circumstances the eggs hatch and larvae leave the cyst to seek a host plant. Ellenby (*23*) showed that even when exposed to stimulating root leachings all the eggs in a given cyst do not hatch at once. Metabolic byproducts of larval activity seem to inhibit further hatching for a limited period. Hatched larvae contain stored nutriment sufficient to permit activity without food for a short time. Franklin (*29*) found that such free larvae could survive in the soil 9 months but could not survive 20 months.

The natural rate of death of a golden nematode population in the absence of the host crop depends chiefly on the rotation crop. Observations by the writer have shown that in one instance a reduction of 75 percent in the viable eggs and larvae per unit of soil occurred in the first season; this corresponded to a 2- to 5-percent reduction of viable cysts. In another instance, with a different rotation crop and season, approximately a 30-percent reduction in viable cysts resulted during the first year.

Selection of crops to be used in rotation involves a balance of financial return of the rotation crops and the benefits in hatching stimulation of golden nematode larvae due to root leachings of these crops. Rough bluegrass and Kentucky bluegrass (*Poa trivialis* L. and *P. pratensis* L.), corn, lupines, barley, oats, wheat, and rye have been rated as fairly effective rotation crops in the descending order named. The potato and tomato are the only commercial crops known to act as hosts of this parasite. For soils also containing root-knot nematodes, legumes such as clover and alfalfa should be avoided, as root-knot populations might be increased to such a level that the eventual potato crop would suffer injury. Cash crops such as cabbage, turnips, parsnips, carrots, and lettuce should be considered on their individual merits as sources of income, because none of these has been shown to reduce golden nematode soil infestations any more than soil fallow, and most of them would increase root-knot populations.

SOIL FUMIGATION

Reinmuth (*52*) successfully treated soil containing the golden nematode with carbon disulfide at the rate of 2,200 pounds per acre. Yields of potatoes were increased 60 percent as a result of a single application, 140 percent after a double application.

Miles (*44*), in corroborating experiments of earlier workers, obtained increased yields both by the application of naphthalene, of calcium cyanide, and of calcium cyanamide, while Hurst and Franklin (*36*) obtained somewhat inconsistent results with calcium cyanamide.

Smedley (*53*), O'Brien, Gemmell, Prentice, and Wylie (*47*), and Edwards (*19*) have all experimented with chloroacetates. Calcium chloroacetate at the rate of 3 to 5 cwt. per acre gave increased yields and brought about a minor reduction in new female nematodes on the roots.

Smedley (*54*) obtained field control with isothiocyanates. Ellenby (*21*) obtained control with allyl isothiocyanate, which, at 10 pounds per acre absorbed on peat moss and placed in the row, gave remarkably increased yields. Mai and Lownsbery (unpublished data) were unable to verify these results.

Chitwood (*13*) and Chitwood and Buhrer (*14*) summarized preliminary work on soil fumigants against this pest. Since the publication of these results, more extensive work has been carried out with certain more promising soil fumigants. This work has been conducted both in pilot plots of 4 by 6 feet and in larger field plots. Results are summarized in tables 6 to 8.

PILOT PLOTS

In the fall of 1946, 96 plots were set up, each plot 4 by 6 feet, surrounded by a galvanized iron barrier, and filled with heavily infested soil taken from a potato field. A split-plot design with 4 replications was used. Whole plots received 4 application rates of 6 treatments, including the control. Soil fumigants were applied in a single application at the rates of 23.5 and 47 gallons per acre. Six weeks thereafter half the plots were turned over and given a second application at the same rate. Each plot was planted in the spring of 1947 with 10 seed pieces of certified Green Mountain variety potatoes and 1.7 pounds of 5–10–5 fertilizer (this is equivalent to 1¼ tons of fertilizer per acre). All plants were dug in June, the tubers weighed, and the roots preserved for laboratory indexing by the washed-root technique. Yield records are relative, as plants were very immature at harvest.

Dichloropropene-dichloropropane mixtures and ethylene dibromide mixtures caused increased yields and reduced the nematode population significantly as compared with controls in nearly every instance. The minimum dosage rate, 23.5 gallons per acre in a single application, was significantly less effective than higher dosage rates. The moderate rate, 47 gallons per acre in a single application, appears to be the best selection economically. Two applications of 23.5 gallons were better than one application of 47 gallons per acre, but the difference is not significant. The advantage in the double treatment is probably due to death of nematodes in surface soil.

Table 6.—*Results of soil fumigation tests against golden nematode, 1947 pilot plots* [1]

Chemical and test	Trade name [2]	Application per acre	Mean values with standard error [3]		
			Tuber weight	Female nematodes—	
				Per plant	Per gram root
Test 1		*Gallons*	*Ounces*	*Number*	*Number*
Dichloropropene-dichloropropane	D-D	23. 5	38. 7** ± 5. 0	1, 460* ± 185	99 ± 34
	Df N	23. 5	35. 5* ± 5. 0	1, 618* ± 195	110 ± 29
Ethylene dibromide	Df W10	23. 5	28. 2* ± 3. 3	1, 617* ± 100	91 ± 48
	Isc D	23. 5	26. 2 ± 6. 4	1, 378* ± 607	110 ± 53
Ethylene chlorobromide	Isc C	23. 5	23. 0 ± 2. 5	6, 316 ± 817	325 ± 34
None			13. 7 ± 3. 1	4, 631 ± 1, 012	279 ± 72
Test 2					
Dichloropropene-dichloropropane	D-D	47	51. 0 ± 13. 8	235*** ± 75	19** ± 7
	Df N	47	36. 7* ± 5. 9	528*** ± 132	36** ± 10
Ethylene dibromide	Df W10	47	44. 5* ± 7. 5	600*** ± 121	31** ± 5
	Isc D	47	30. 5 ± 4. 3	2, 285* ± 865	125* ± 40
Ethylene chlorobromide	Isc C	47	18. 2 ± 2. 6	4, 088 ± 900	232 ± 33
None			18. 5 ± 3. 4	5, 536 ± 697	312 ± 62
Test 3					
Dichloropropene-dichloropropane	D-D	[4] 23. 5×2	37. 7 ± 8. 5	279* ± 202	19 ± 7
	Df N	[4] 23. 5×2	33. 0 ± 10. 6	250** ± 121	19 ± 8
Ethylene dibromide	Df W10	[4] 23. 5×2	41. 5* ± 5. 3	431* ± 65	24 ± 6
	Isc D	[4] 23. 5×2	28. 2 ± 3. 3	1, 320 ± 310	70 ± 15
Ethylene chlorobromide	Isc C	[4] 23. 5×2	31. 5 ± 8. 3	2, 838 ± 757	203 ± 71
None			21. 2 ± 4. 8	3, 453 ± 853	285 ± 131

Test 4					
Dichloropropene-dichloropropane	D-D	[4] 47 ×2	52.7** ± 5.9	38*** ± 21	4* ± 3
	Df N	[4] 47 ×2	58.2*** ± 5.1	69*** ± 30	16* ± 11
Ethylene dibromide	Df W10	[4] 47 ×2	38.2 ± 8.9	52*** ± 25	4* ± 2
	Isc D	[4] 47 ×2	47.2* ± 8.7	539** ± 195	28* ± 10
Ethylene chlorobromide	Isc C	[4] 47 ×2	21.5 ± 5.2	3,494 ± 1,210	212 ± 62
None			18.7 ± 2.6	4,139 ± 619	308 ± 85

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[1] Each figure is a mean of 4 replicate plots, 10 plants per plot.

[2] D-D=product of Shell Chemical Corp.
Df=Dowfume (various products, as indicated, of the Dow Chemical Co.)
Isc=Iscobrome (various products, as indicated, of Innis, Speiden & Co.)

[3] Values of *t* required for significance at 0.05 level, 2.447; at 0.01 level, 3.707; and at 0.001 level, 5.959; *,**,***, differing from controls with odds of 19:1, 99:1, and 999:1, respectively.

[4] 2 applications were made with a 6-week interval between applications. Soil was turned during this time.

TABLE 7.—*Summary of results recorded in table 6, omitting ethylene chlorobromide, of soil fumigation tests against golden nematode, 1947 pilot plots*

Chemical	Application per acre	Mean values with standard error [1]		
		Tuber weight	Female nematodes—	
			Per plant	Per gram root
	Gallons	*Ounces*	*Number*	*Number*
Dichloropropene-dichloropropane, 8 replicates each.	23. 5	37. 1*** ± 3. 3	1, 539*** ± 234	105*** ± 22
	47. 0	43. 9** ± 7. 0	381*** ± 91	28*** ± 5
	[2] 23. 5×2	35. 4* ± 6. 2	268*** ± 116	19*** ± 6
	[2] 47. 0×2	55. 5*** ± 3. 7	54*** ± 18	10*** ± 6
Ethylene dibromide (10 percent by volume), 8 replicates each.	23. 5	27. 2* ± 3. 3	1, 497*** ± 457	100*** ± 33
	47. 0	37. 5*** ± 4. 7	1, 483*** ± 502	78*** ± 26
	[2] 23. 5×2	34. 9*** ± 3. 9	878*** ± 178	47*** ± 11
	[2] 47. 0×2	42. 7*** ± 6. 0	296*** ± 133	15*** ± 8
None, 16 replicates each		18. 1 ± 1. 7	4, 439 ± 418	296 ± 41

[1] Values of *t* required for significant differences from controls at 0.05 level, 2.074; at 0.01 level, 2.819; and at 0.001 level, 3.792; *, **, ***, differing from controls with odds of 19:1, 99:1, and 999:1, respectively.

[2] 2 applications were made with a 6-week interval between applications. Soil was turned during this time.

As reported here, there is no significant difference between dichloropropene-dichloropropane mixtures and ethylene dibromide mixtures, when used at the same rates.

Ethylene chlorobromide mixtures were ineffective in this series of tests.

FIELD PLOTS

Large-scale field plots were set up in cooperation with the Bureau of Entomology and Plant Quarantine in the fall of 1944. These plots were originally 1 acre in size, later split to form one-half acre plots. The field was indexed for cyst content on the basis of 240 one-ounce soil samples in the fall of 1944. Plots were so arranged as to have equivalent inoculum in treated and untreated plots (table 8, see viable cyst index, 1944). Half of the plots were plowed and treated by the Bureau of Entomology and Plant Quarantine, using their tractor applicators, and then rolled, the other half being left as controls.

Treatment was made by the continuous-flow method of injection at 12-inch intervals and a depth of 6 inches. This method of application is described in some detail by Popham (*50*). Dosage rates were 450, 600, 900 (two plots), and 1,200 pounds per acre of D-D (dichloropropene-dichloropropane mixture).

Each plot was divided into 6 strips, 4 planted to oats and rye as rotation crops and 2 to Green Mountain potatoes, in 1945. The standard practices followed included the application of 1¼ tons of 5–10–5 fertilizer and the planting of 15,000 potato plants per acre. Records were kept of the number of female nematodes on root systems from each strip, the number of viable cysts per 10 grams of soil in 16 samples

TABLE 8.—*Effects of soil fumigation of field plots with D-D against golden nematode of potatoes, 1944–46*

Year in which soil was treated	Mean values with standard error on examination dates in—							
	1944 (pretreatment)	Replicates	1945	Replicates	1946			
					Rotation 1945	Replicates	No rotation 1945	Replicates
VIABLE CYSTS PER 10 GM. SOIL IN FALL								
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Soil not treated	5. 5 ± 1. 5	10	6. 10 ± 1. 32	10	3. 74 ± 0. 55	5	5. 62 ± 1. 63	5
1944	5. 0 ± 1. 3	10	. 94 ± . 68	10	. 66 ± . 35	5	3. 17 ± 1. 38	5
1945	5. 1 ± 1. 6	5	5. 03 ± 2. 27	5	. 97 ± . 64	7	. 75 ± . 71	5
1944 and 1945	5. 3 ± 2. 1	5	. 16 ± . 03	5	. 02 ± . 01	5	. 01 ± . 01	5
All					1. 31 ± . 73	12	2. 18 ± . 73	10
FEMALES COLLECTED PER PLANT (APPROXIMATE 4 GM. OF ROOT), AS DETERMINED BY WASHED-ROOT TECHNIQUE (JUNE SAMPLES)								
Soil not treated			1, 068 ± 331	10	2, 310 ± 636	5	4, 938 ± 843	5
1944			172 ± 158	10	132 ± 94	5	1, 300 ± 705	5
1945			1, 158 ± 406	5	137 ± 102	7	256 ± 219	5
1944 and 1945			12 ± 8	5	6 ± 3	5	6 ± 2. 5	5
All			607 ± 172	20	599 ± 246	12	1, 625 ± 166	10
YIELDS OF GREEN MOUNTAIN VARIETY POTATOES								
			Bushels per acre		*Bushels per acre*		*Bushels per acre*	
Soil not treated			209 ± 25	10	215 ± 17	5	181 ± 42	5
1944			306 ± 19	10	250 ± 15	5	249 ± 35	5
1945			209 ± 38	5	262 ± 13	7	248 ± 2	5
1944 and 1945			308 ± 24	5	247 ± 18	5	236 ± 23	5
All					245 ± 7. 9	12	229 ± 2. 5	10

from each strip, and the yield in bushels of potatoes per acre. The results (all dosage rates combined) are presented in the 1945 column of table 8. Yields were significantly greater in plots given treatments than in control plots, but there were no significant differences between treatments.

Half of each of the plots treated in 1944 and half of each of the plots not treated in 1944 were treated in the fall of 1945. Dosage rates were 250 and 450 pounds per acre in single and double applications. The latter consisted of treating the soil, rolling, then disking a month later, and again treating and rolling. Thus one-fourth of the land was untreated in any year, one-fourth was treated in 1944, one-fourth in 1945, and one-fourth in both 1944 and 1945.

Results are given in the 1946 columns of table 8. Yield differences were not significant, although the trend was in favor of treatment and in favor of rotation. Differences in nematode population were highly significant. Considering dosage rates, the single application of 250 pounds per acre was not so efficient in controlling nematodes as other rates. Treatments at not less than 450 pounds per acre were adequate for the production of normal crops in both 1945 and 1946 without additional treatment. The nematode population, however, had returned to approximately the original level after the second crop of potatoes. Quite aside from the experimental pattern described above, a test was made in which D-D was sprayed on top of the soil instead of being injected. This procedure was found to be ineffective.

Special field plots were treated with D-D and Dowfume N in the fall of 1946. In the spring of 1947 cysts taken from that soil between 1 and 6 inches deep showed 93- to 100-percent reduction in viability; in the top inch 72- to 74-percent reduction in viability, and in the plow sole (7- to 8-inch depth) 83- to 92-percent reduction in viability. Further segregation of profile soil samples showed that soil-fumigation treatments were totally ineffective in the top quarter inch of soil.

SOIL FUMIGATION CONCLUSIONS

The foregoing experiments indicate that dichloropropene-dichloropropane mixtures and ethylene dibromide mixtures are both effective as soil fumigants for the control of the golden nematode of potatoes.

Soil should be well tilled and have a reasonable moisture content at time of application. Immediately after treatment, the soil should be rolled. Best results have been obtained in fall treatments, with weekly mean temperatures of 60° to 70° F. Annual treatment at the rate of 23.5 gallons per acre might be economically sound but cannot be recommended as adequate for long-term nematode control at the present time, as the nematode population would return to its previous level after each crop of potatoes and dispersal would not be controlled.

In order to maintain the nematode population in a status quo and retain sound potato production, a biennial treatment would be satisfactory, using 23.5 gallons of D-D, Dowfume N, Dowfume W 10, or Iscobrome D, followed after 3 to 6 weeks by the turning of the soil and a second treatment at the same rate. This would not be sufficient, however, to prevent spread of the disease. Annual treatment, on the other hand, would reduce the nematode population drastically and consequently would reduce the hazard of spread. The latter treatment is preferred for that reason.

Fumigated soil should be properly aerated before planting. In some instances soil-fumigant residues have persisted for remarkably long periods. These residues might conceivably cause injury to plant or product and might be cumulative. Further information is essential on this phase of the problem.

PRECAUTIONS

Most soil fumigants are corrosive to metals, some of them extremely so, and applicators should be emptied and cleaned immediately after use, following the manufacturer's directions.

The dichloropropene fumigants are inflammable as well as all mixtures where naphtha or a similar diluent constitutes a considerable portion of the volume; hence, precautions should be taken to avoid igniting the fumes by fire or sparks.

All soil fumigants are toxic to humans and animals, at least to some degree, but none are dangerous to the operator when properly handled. The manufacturer's directions will provide information regarding any special precautions that should be taken when handling particular fumigants.

The following precautions should be taken with all soil fumigants.

1. **Avoid prolonged breathing of the fumes, even though they may not be irritating or have a pronounced or distinctive odor.**
2. **Do not allow the liquids to remain in contact with the skin. Wash off promptly with soap and water and leave the exposed area open to the air for a short time.**
3. **If the liquids are spilled on clothing, remove the garments, including shoes or gloves, without delay. Usually it is not advisable to wear gloves.**
4. **Never, under any circumstances, take the risk of getting the liquids into the eyes or mouth.**

TUBER DISINFESTATION AND DISINFECTION

Since the golden nematode is superficial and does not disfigure the tubers or affect their edibility, any method that would remove infested soil from tubers or destroy such nematodes as might adhere to them would greatly reduce dispersal of the disease organism.

Machmer (*40*) reported 90-percent reduction in cysts left on tubers after jet washing of potatoes freshly dug from a heavily infested field. It is practically impossible to remove all the nematodes from such potatoes, particularly if they are dug before the potatoes are mature. Nematodes remain in the potato eye even after severe hand scrubbing. When tubers have hardened in the field fewer nematodes remain attached, and if such potatoes are stored for a length of time it is difficult to find a cyst remaining attached on batches of literally hundreds of potatoes. Thorough washing of field-hardened, stored potatoes will certainly reduce the possibility of dispersion of the nematodes by tubers to a minimum.

Chemical disinfestation and heat disinfestation of tubers have been attempted by several workers. Franklin (*31, 32*) found a treatment in 1 percent formalin for 5 minutes at 125° F. quite promising. Fenwick (*27*) found the sulfur dioxide treatment effective—2 sulfur candles per 1,000 cubic feet in a water-saturated atmosphere for 24 hours. Neither treatment had any marked effect on the tubers as far as their use for seed was concerned, but neither would be desirable as treatments for tubers intended for food. Tests by Division of Nematology personnel have shown methyl bromide and ethylene chlorobromide to be ineffective at temperatures and dosages tolerated by tubers.

Tests have also shown that treatment in 1 percent ammonia at 110° F. for 5 minutes reduced the viable nematodes 98.4 percent (2 replications containing a total of 1 viable cyst in 62 potential viables) and 99.9 percent (5 replications with a mean of 1 new female per treated sample as compared to 1,126 in controls). This method was not developed further because of the difficulty of confining the ammonia fumes in large-scale applications.

At the present time, the use of chemicals for disinfestation of tubers intended for food does not offer much promise as a practical, large-scale method to kill all of the nematodes and at the same time not injure the storage quality of the tubers nor leave in the tubers traces of chemicals that might be poisonous or that would affect palatability.

CONCLUSIONS

Once soil has become infested with golden nematodes, it is possible to grow satisfactory crops only on lightly infested soil, that is, soil which contains only comparatively few golden nematode cysts with viable larvae. The number of larvae in the soil can be controlled by crop rotation or soil fumigation. If the number is small enough, rotations that include potatoes every third year can be used, but if the number of nematodes is very large, a satisfactory crop can be grown only every fifth or sixth year. Soil fumigation is also effective in reducing the number of larvae in the soil, and one satisfactory crop can be grown if the soil is fumigated with two applications of 23.5 gallons each of dichloropropene-dichloropropane mixture or 20 percent (by volume) ethylene dibromide mixture, the soil being turned over in the interval between applications. Neither the 6-year rotation nor soil fumigation is a practical method of eliminating the nematodes from the soil, but rotation or fumigation must be repeated before each crop of potatoes for an indefinite period.

Spread of the cysts can be minimized by regular inspection to determine areas and degree of infestation. When infestations are located, the crop should be harvested only when fully mature and the tubers should be thoroughly washed and marketed only in paper bags for consumption in metropolitan areas. Shipments to processing plants may be made in bulk. Movement of topsoil from infested lands should be limited to destinations where there is no opportunity for cysts to come into contact with the roots of host plants.

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